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Overland Flow Treatment of Poultry Processing Wastewater in Cold Climates

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16. ABSTRACT

Land treatment of wastewater using the overland flow process has been effectively used in warm climates. This project evaluates a full-scale wastewater treatment facility emphasizing the overland flow process in northern Indiana, which has a cold climate. The other processes include mechanical pretreatment, a storage lagoon, a lagoon for batch chemical treatment of the overland flow effluent, and rapid infiltration.

Overland flow systems are usually used on low permeability soils, but in this study a sandy loam with a high permeability was used. This was accomplished by placement of a percolation barrier 15 cm below the surface.

The report describes the design, construction and operation of the system and includes the many problems associated with cold weather. The efficiency of the overland flow process via seasons is given along with recommended changes in design and operation.

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OVERLAND FLOW TREATMENT OF POULTRY PROCESSING WASTEWATER IN COLD CLIMATES

by

Lloyd H. Ketchum, Jr.
Arthur J. Cunningham
Robert L. Irvine
University of Notre Dame
Notre Dame, Indiana 46556

Contract No. R 804677

Project Officer

Jack L. Witherow
Land Treatment Task Force
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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FOREWORD

The Environmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management, techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs including the development and demonstration of soil and other natural systems for the treatment and management of municipal wastewaters.

The overland flow treatment process uses the soil surface and has a point discharge. Although irrigation of land with wastewater has been practiced for centuries, the overland flow process was first tried about 1960. Research on this initial facility was one of the first efforts undertaken by this laboratory. Development of the process has been at locations where freezing seldom occurs. This project evaluates the potential for expanding application of the process in northern, colder states. The full-scale facilities used in this investigation are in northern Indiana. The facilities treated wastewater from a duck slaughterhouse. This wastewater is as amenable to biological treatment as domestic sewage and has similar concentration of nutrients and solids.

This report contributes to the knowledge which is essential for the EPA to meet the requirement of environmental laws and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental
Research Laboratory

ABSTRACT

Land treatment of wastewater using overland flow methods has been effectively used in warm climates. This study is an evaluation of a duck processing plant wastewater treatment facility, including overland flow, in northern Indiana, a cold climate. The emphasis of the study was the evaluation of the overland flow system, but the treatment system included mechanical pretreatment facilities, a storage lagoon, a lagoon for batch chemical treatment of the overland flow effluent for disinfection and phosphorus, five-day biochemical oxygen demand and suspended solids reduction, and rapid infiltration for additional treatment and effluent disposal.

Overland flow systems typically are limited to low permeability soils. This site was located on an Oshtemo Series, a sandy loam soil with very high permeability. To accomplish overland flow treatment, the topsoil was first stripped from the site. Next, the site was graded to provide a uniform slope of 4% downhill and level across the site. Bentonite was mixed into a 5-centimeter layer to provide a percolation barrier, then the topsoil was replaced in a 15-centimeter layer and seeded with a mixture of Kentucky 31 fescue and perennial ryegrass.

This report presents the monitoring data and describes the design and operation of the system, and construction costs are given. The section describing the operation includes a detailed evaluation of the many problems encountered including those associated with the cold weather operation. This discussion should benefit others to avoid similar problems.

This report was submitted in fulfillment of Grant No. R-804677 by the University of Notre Dame under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from November 1, 1976 to October 31, 1979 and was completed as of January 30, 1980.

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CONVERSION TABLE AND ABBREVIATIONS

Multiply Metric Units	by	To Obtain English Units
liters/second (l/sec)	15.85	gallons/minute (gpm)
cubic meters (m^3)	35.314	cubic feet (ft^3)
meters (m)	3.28	feet (ft)
kilograms (kg)	2.205	pounds (lbs)
cubic meters (m^3)	$2.64x10^{-4}$	million gallons (MG)
liters (L)	0.264	gallons (gal)
hectares (ha)	2.471	acres
centimeters (cm)	0.3937	inches (in)
cubic meters/day (m^3/d)	0.1835	gallons/minute (gpm)
kilowatts (kW)	1.341	horsepower (hp)

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SECTION 1

INTRODUCTION

Conventional wastewater treatment is often an economic burden for rural communities and small businesses. The approaching enforcement of the Best Available Technology discharge limitations is putting additional economic stress on rural areas. The United States Environmental Protection Agency (USEPA) has recently encouraged use of land treatment as an alternative to conventional treatment. Construction and operation of land treatment facilities is relatively economical and simple, when properly designed (1).

Overland flow treatment of wastewater is one of the land treatment alternatives now being encouraged. Wastewater is applied at the top of a graded impermeable slope, and is treated chemically and biologically as it flows down the slope. The effluent is recovered at the foot of the slope for further treatment or discharge.

The advantages of overland flow treatment include the feasibility of applying raw wastewater which has been screened, and the land requirements are less than for irrigation systems. Past experience has shown that high strength organic wastewater can be treated to an effluent quality equal or better than secondary effluent from a conventional plant (2). Overland flow systems also can take advantage of a site with impermeable soil.

One disadvantage of overland flow treatment is that impermeable soil is required at the treatment site. Overland flow treatment systems usually require more operating labor than other land treatment methods (3). A disadvantage of land treatment in general is the adverse affect of cold weather on effluent quality. Due to these limitations, most overland flow systems to date have been constructed on impermeable soils in the southern region of the United States.

This overland flow system was constructed at the Culver Duck Farm, a family owned and operated farm and slaughterhouse. The farm was located in Middlebury, Indiana, a rural town near the Indiana-Michigan border. Soil at the site was a permeable loamy sand. The mean monthly temperatures for December, January and February are normally approximately -5° to -10°C. The system included a fine screen, gravity grease separator, an optional lagoon for storage (treatment was provided when included in the treatment train and algae production changed the character of the wastewater), two parallel overland flow plots, a lagoon to collect the overland flow effluent and allow batch chemical treatment and a rapid infiltration area for effluent polishing and disposal.

The overland flow plots were constructed on a permeable loamy sand. That was made possible by construction of a bentonite barrier under the topsoil. During wastewater application, the void volume in the permeable soil above the barrier was first filled with water. No effluent was observed until all the voids were filled and water running along the surface reached the end of the plot.

The site was well suited for an irrigation system. In retrospect a slow rate system would have been a better alternative. However, the grant was awarded for another site which was better suited for overland flow treatment. Unfortunately, the operators of the original slaughterhouse discontinued operation and the Culver Duck Farm was used as an alternative site. The overland flow plots were needed to reduce the nitrogen concentration prior to the rapid infiltration to prevent percolation waters with greater than 10 milligrams per liter (mg/ℓ) nitrogen at the Culver Duck Farm site.

The objectives of the study were as follows:

1. To demonstrate the operation of an inexpensive simply operated slaughterhouse (more specifically a duck processing plant) wastewater treatment facility which will meet the 1983 National discharge limitations.

2. To evaluate the use of overland flow treatment in a cold climate.

3. To evaluate the effectiveness of batch chemical treatment directly in a lagoon for phosphate and suspended solids removal and disinfection.

4. To develop basis of design for the overland flow treatment system, and present these design details sufficiently clear to allow their use by slaughterhouse operators with little technical assistance.

5. To present estimates of costs to allow economic comparison of this system to others capable of treating these type wastes.

In addition, an evaluation of the bentonite seal used to allow overland flow treatment at sites with permeable soils has been included.

SECTION 2

CONCLUSIONS

Overland flow was an effective method of treating duck slaughterhouse wastewater. From 70% to 99% of the mass of five-day biochemical oxygen demand (BOD_5), suspended solids and nitrogen applied was removed under a wide range of operating conditions.

The overland flow plots usually met the proposed Best Available Technology effluent guidelines for suspended solids. Grease and oil in the effluent was below these guidelines. Ammonia and BOD_5 concentrations were often in excess of these guidelines. The periods when proposed effluent guidelines were not met were mainly freezing periods, especially when the site was free of snow. Although treatment failed to meet proposed guidelines when snow covered the fields, effluent quality was superior to similar periods without snow cover.

More time was required for routine operation and maintenance during the winter than during other seasons. Mechanical problems led to sporadic wastewater application, thus limited conclusions can be drawn from data collected during the winter. Data presented suggests that winter wastewater application allowed the development of a soil microbial population which was capable of wastewater treatment in sub-zero temperature. The low hydraulic loading required during cold weather would necessitate storage of some or all wastewater produced at the site from December through February.

In-plant wastewater strength and volume reduction would be needed at the slaughterhouse. That would help eliminate the need to use high loading rates to the overland flow plots, and would add a flexibility of operation.

Air temperature appeared to be the most important factor affecting effluent quality during winter and early spring, but not during warmer periods. Effluent quality was most sensitive to temperature fluctuations when the air temperatures were near 0°C. Sudden decreases in air temperature from above to below 0°C caused a significant decrease in effluent quality.

Daily drying periods of from eight to 14 hours were not sufficient to prevent grass damage during the Spring. That problem was avoided by applying wastewater 24 hours/day for several days, followed by two or more days of drying. A similar cycle may also prove beneficial at more conventionally constructed overland flow sites located on impermeable soil. At the site, the permeable soil above the bentonite seal required those relatively long drying periods, and the continuous periods of wastewater application appear to be warranted.

Application of lagoon effluent during periods of high algae concentrations resulted in a doubling of effluent BOD_5 and nitrogen, and a four-fold increase in suspended solids.

Improvement of the pretreatment system is necessary to prevent mechanical problems caused by large solids in the processing wastewater. Elimination of those persistent problems would allow reliable application of the wastewater instead of lagoon water.

Shortcircuiting of wastewater on the overland flow plots caused problems at the beginning of operation. Small earthen dikes were built to redirect flow to dry areas. This method eliminated shortcircuiting problems.

Chemical treatment and disinfection of the overland flow effluent, collected in a lagoon at the foot of the plots, proved effective for phosphate and suspended solids reduction and disinfection. The lagoon also provided for control of overland flow effluent. Low quality effluents were collected and returned for further treatment.

Design procedures are described and sufficiently simple to allow slaughterhouse operators to used overland flow treatment with little technical assistance. Costs of these systems can also be estimated using information provided herein.

Bentonite clay applied at 5 kilograms per square meter (kg/m^2) and mixed to 5-centimeter (cm) depth was effective in decreasing permeability of a sandy soil from 0.02 centimeters per second (cm/sec) to 3 x 10^{-5} cm/sec. This permeability is acceptable for overland flow, according to USEPA design guidelines (3).

SECTION 3

RECOMMENDATIONS

Overland flow should be considered as a wastewater treatment alternative at sites with permeable as well as impermeable soils. Application of more than 5 kg/m^2 of bentonite is recommended to ensure a better percolation barrier at future sites. At the site, future monitoring is recommended to determine the effective life of the seal.

In systems requiring increased phosphate removal, disinfection, or a greater assurance of suspended solids reduction, a small lagoon should be constructed to collect the overland flow effluent. This provides opportunity, using sample batch chemical treatment and controlled discharge, to improve effluent quality. This relatively inexpensive treatment is well suited for use in conjunction with overland flow.

Research should be undertaken to determine optimum wastewater application cycles. Experience at the site suggests that 24 hours per day application for several days, followed by two or three days of drying, is a cycle which deserves future investigation.

Winter operation needs to be investigated further. The study indicated that some degree of treatment is possible in the winter, but that loading rate must be reduced, and unsatisfactory effluent returned for further treatment. Winter wastewater application is recommended to develop a microbial population capable of treating the wastewater immediately following the spring thaw.

Further investigations are necessary to determine the effect of sudden decreases in temperature in late fall and early spring. It may be neccessary to stop wastewater application during these short cold spells.

Application of lagoon wastewater to an overland flow plot should be avoided if possible. Operators of systems using storage lagoons prior to overland flow treatment, are recommended to by-pass these lagoons during peak algae growing periods. Removal of sufficient grit and solids to prevent pump and nozzle plugging is recommended when lagoons are by-passed or raw wastewater is applied directly to overland flow plots.

SECTION 4

TREATMENT PLANT COMPONENTS

Treatment plant components are shown on Figure 1 and are described briefly in the following sections. These components have been grouped into five categories. Pretreatment facilities were located in the processing plant and included a fine screen and a gravity grease separator. A lagoon provided storage and primary-type treatment. During some operating periods, the lagoon was by-passed and raw wastewater was applied directly to the overland flow plots. Two overland flow plots were operated in parellel and were the primary focus of the study. Effluent from the overland flow plots was collected in another lagoon where batch chemical treatment was provided to precipitate phosphorus and improve suspended solids removal, including algae. The last component was a land treatment facility designed for rapid infiltration. No monitoring of that effluent was conducted because it was intended primarily as a means of disposing of the treated wastewater. However, those types of systems have been studied and a highly polished effluent was expected. The system investigated provided treatment for only the processing plant wastewater, domestic wastewaters were treated in another system. A building referred to as the control building was constructed to facilitate flow monitoring and sample collection, and was needed only for the study. That building housed the overland flow influent meters and effluent weirs and recorders.

The final size of the facilities and actual wastewater flow rates varied from the values used for design. The actual values are reported and discussed in the following sections, however the values used for design purposes were as follows:

	Process
Production	3000 ducks per operating day
Operating days	Winter 2 days per week Summer 3 to 4 days per week
Live weight	6.4 lb per duck 2.9 kg per duck
Waste volume	6 gallons per duck 23 liters per duck 50% assumed loss on overland flow plots

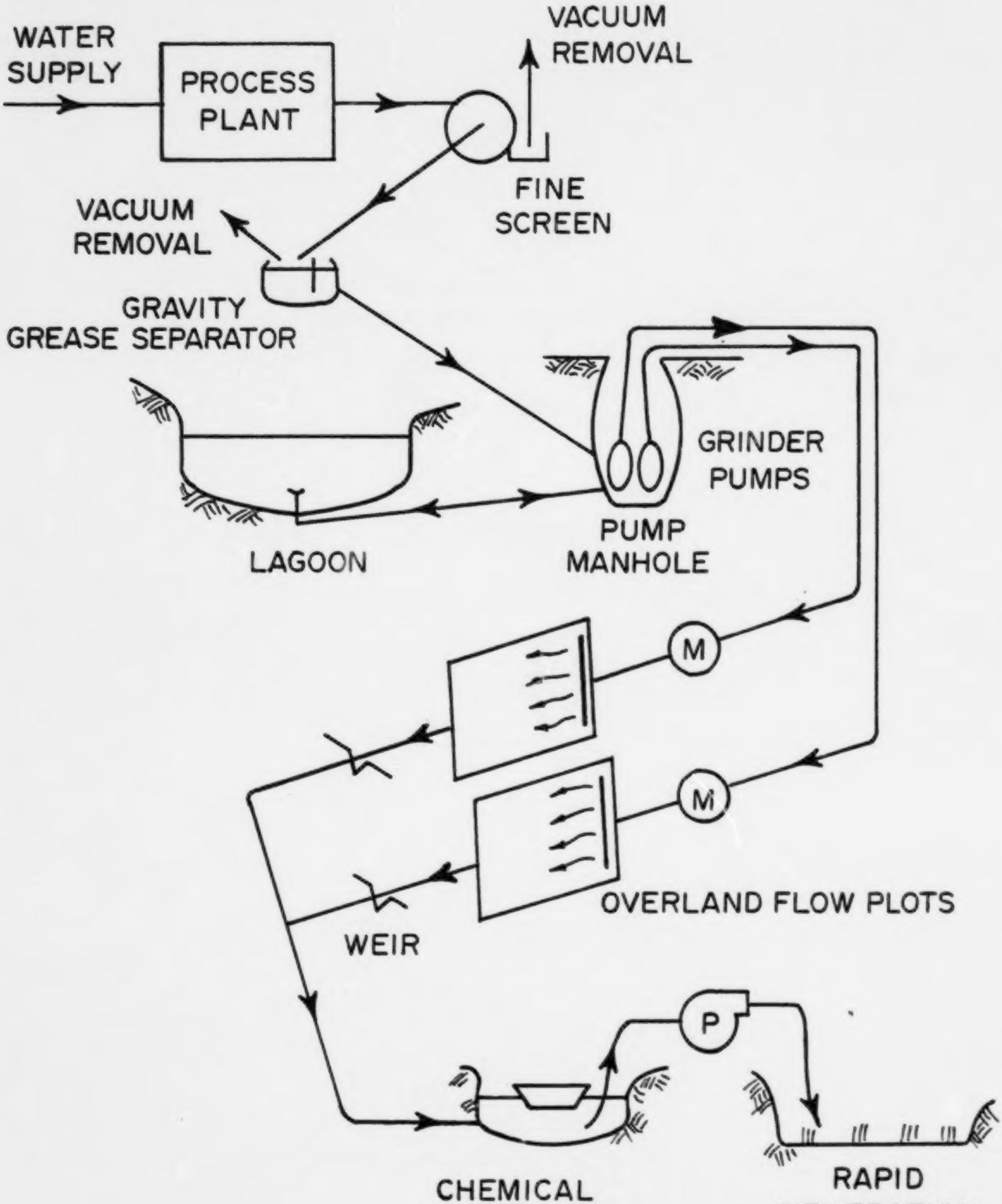
WATER SUPPLY
PROCESS PLANT
VACUUM REMOVAL
FINE SCREEN
VACUUM REMOVAL
GRAVITY GREASE SEPARATOR
GRINDER PUMPS
LAGOON
PUMP MANHOLE
M
M
OVERLAND FLOW PLOTS
WEIR
P
CHEMICAL TREATMENT
RAPID INFILTRATION

Figure 1. Wastewater treatment system schematic.

Treatment Facilities

Lagoon	0.46 MG 1740 m^3
Overland Flow Plots	2 plots 65 ft x 260 ft (0.39 acres) 20 m x 79 m (0.16 hectares) 4% Slope Application rates 3 in/week 7.6 cm/week
Chemical Treatment Lagoon	0.13 MG 490 m^3 Mechanical Aeration 1 Hp
Rapid Infiltration Area	0.11 Acres 0.045 ha

PRETREATMENT

All wastewaters and process waters from the duck processing plant flowed by gravity into a single line designed to pass through the fine screen. The screen was designed to remove pin feathers, offal and other solids, and is described as follows:

Equipment: Fine screen
Type: Hydrocyclonics Rotostrainer
Rated capacity: 6.3 liters/second (ℓ/sec) (100 gpm)

A gravity-type of grease separator immediately followed the fine screen, and is described as follows:

Unit: Gravity grease separator
Size: Width: 2.7 m (9.0 ft)
Length: 1.8 m (6.0 ft)
Liquid depth: 1.0 m (3.17 ft)

Solids storage capacity: 340 kg (750 lb)

LAGOON

Wastewater flowed by gravity from the gravity grease separator into a manhole. The manhole had a gravity sewer line running into the lagoon. The outlet pipe led to a point near the lagoon bottom. The manhole (referred to as the pump manhole) was initially equipped with two grinder pumps. These are described as follows:

Equipment: Grinder pump
Type: Hydro-O-Matic pumps
Hydrogrind 2 Hp

Rated capacity:	Head, ft	Discharge, gpm
	61	0
	60	5
	58	10
	55	15
	52	20
	48	25

When the pumps were not in operation, effluent from the pretreatment facilities flowed by gravity into the lagoon. When the pumps were in operation, and the processing plant was in operation, raw wastewater was pumped directly to the overland flow plots. During weekends, night-time or days when the processing plant was not in operation, the pumps pulled water backwards through the sewer line from the lagoon, and pumped lagoon-stored water to the overland flow plots.

After May, 1979, these pumps were removed from the pump manhole because of several instances of pump damage due to solids passing the preliminary treatment facilities. The pumps were then suspended directly in the lagoon so all wastewater was given primary-type treatment in the lagoon prior to discharge to the overland flow plots.

In general, heads on these pump discharge lines raised gradually with time, primarily due to changing amounts of accumulated solids in the pipe line to the overland flow plots, and changing lagoon liquid levels. No attempt was made to valve these lines and control pumping rates. These changes were gradual and resulted in little variation from day-to-day. Flow rates were measured, recorded and found to be between 0.5 ℓ/sec and 1.1 ℓ/sec (8 and 18 gpm).

During some periods of operation, automatic timers were used to turn each pump on and off. Otherwise, manual on-off operation was used.

The lagoon maximum liquid depth was 2.7 m (9 ft) and it had a maximum liquid volume of 2,700 m^3 (0.7 MG).

OVERLAND FLOW PLOTS

Figure 2 shows the details used to design each of the two overland flow plots. The two plots were located side-by-side and generally ran from west to east. The two plots are referred to as the North Plot and the South Plot. A single dike located down the center served to separate the two plots. The actual lengths were approximately as designed, but widths varied slightly resulting in an actual area as follows:

North Plot	0.170 ha	(0.42 acres)
South Plot	0.141 ha	(0.35 acres)

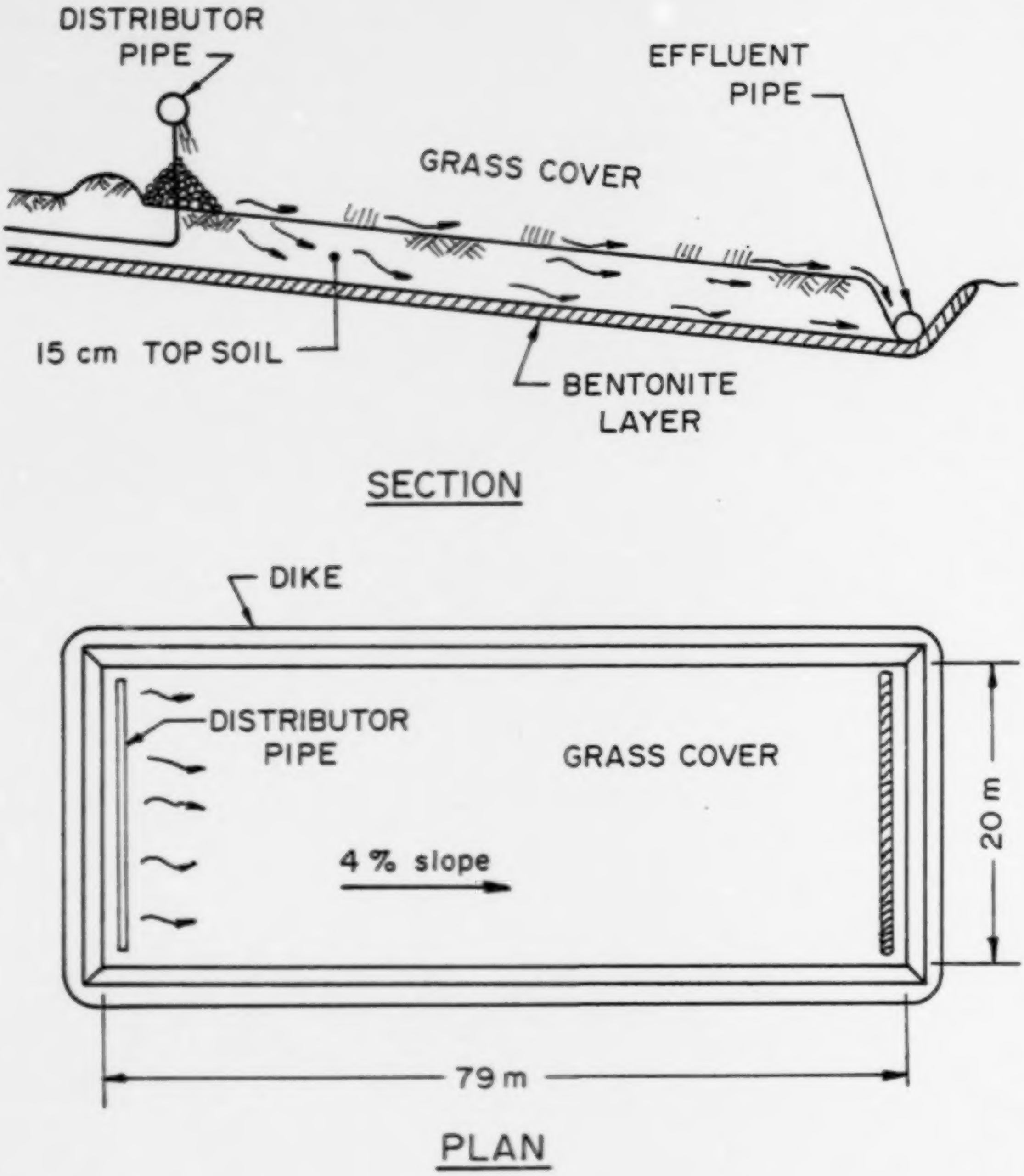
DISTRIBUTOR PIPE
EFFLUENT PIPE
GRASS COVER
15 cm TOP SOIL
BENTONITE LAYER
SECTION
DIKE
DISTRIBUTOR PIPE
GRASS COVER
4 % slope
20 m
79 m
PLAN

Figure 2. Overland flow plot details.

In May, 1979, an additional dike was constructed splitting the South Plot approximately in half lengthwise. The reason for that will be discussed later in detail, but was done to eliminate a problem with leakage from one-half of the plot. The modified South Plot, again the same length but at a reduced width, was as follows:

Modified South Plot 0.087 ha (0.22 acres)

Ordinarily overland flow systems are only suited for soils with low permeabilities. In areas where only permeable soils exist, overland flow treatment has not been practiced. This study addressed this problem, and resulted in development of a method of treating wastewaters, using overland flow technology, on permeable soils. The Culver Duck Farm site is located on a sandy loam soil (U.S. Conservation Service - Oshtemo Series), with a permeability of 5 to 15 cm/h (2 to 6 in/h), which is much greater than that found on the clay-type soils where overland flow has been used.

The site was first stripped of topsoil, then graded to provide a 4% slope downhill and was leveled across the direction of the slope. Bentonite was applied at a rate of about 5 kg/m^2 (1.0 lb/ft^2) to the graded subsoil and was mixed into a depth of about 5 cm (2 in). A 15-cm layer of topsoil (6-in) was then carefully replaced above the bentonite seal and grass was planted. A mixture of Kentucky 31 fescue and perennial ryegrass was used. A more detailed explanation has been included in the section on design and costs.

A ditch was constructed across the foot of each plot and was lined with a bentonite seal similar to the one used under the topsoil, but with twice the bentonite application rate and layer thickness. A 15-cm perforated pipe (6-in) was placed in the ditch to collect the effluent and transport it to a solid pipe which ran to the control building where effluent flow rates were measured.

At the top of each overland flow plot, a pipe leading from one of the pumps located in the pump manhole (later located in the lagoon), came vertically upward out of the ground. A tee connection at the center of a 10-cm diameter (4-in) horizontal pipe was used to direct the flow across the top of the plot. The pipe, the distributor pipe, had 20 holes drilled along the center-line of the pipe and directed horizontally outward toward the plot. Each hole was 2.5 cm in diameter (1 in) and spaced at 0.95-m intervals (3-ft). Beneath the distributor pipe a row of crushed rocks was located to prevent soil erosion and improve distribution of the flow across the top of the plot.

CHEMICAL TREATMENT LAGOON

After flow measurement in the control building, the effluent from both overland flow plots flowed into the chemical treatment lagoon. The maximum lagoon liquid depth was 2.7 m (9 ft) and it had a maximum liquid volume of 565 m^3 (0.5 MG). The overland flow plot effluent was allowed to accumulate to approximately the maximum depth before chemical batch treatment was provided. Typically, treatment consisted of alum addition for phosphorus and

and suspended solids removal and sodium hydrochlorite for disinfection. A floating mechanical aerator (1 hp) was used to provide mixing. After chemical addition and mixing had been completed, the aerator was shut off to allow settling. Later a portable pump was used to draw the lagoon liquid level down to a depth of about 1 m.

RAPID INFILTRATION AREA

The effluent from the chemical treatment lagoon was discharged to the rapid infiltration area. The area was a shallow lagoon-like excavation with a horizontal bottom. The bottom consisted of a highly permeable subsoil and was seeded with a perennial rye grass, primarily to control erosion and weed growth. The total surface area of the bottom was 0.067 ha (0.16 acres).

SECTION 5

OVERLAND FLOW DESIGN AND COSTS

OVERLAND FLOW PLOT CONSTRUCTION

Overland flow systems are usually limited to soils with low permeability. This site was located on a highly permeable sandy loam soil (Soil Conservation Service, Oshtemo Soil Series). This required additional site modification to reduce permeability to levels expected in overland flow plots located on the more usual clay soils. The method selected include use of a bentonite seal located below the topsoil layer. Two different suppliers of bentonite were furnished soil samples taken from the site. Based on hydraulic conductivity tests on these samples, one supplier recommended a minimum application rate of 5 kg/m^2 (1.0 lb/ft^2) and the other 4 kg/m^2 (0.75 lb/ft^2). Both suppliers recommended mixing the bentonite into a 5-cm (2.0-in) layer of soil. Hydraulic conductivities were expected to be reduced to 10^{-8} to 10^{-7} cm/second under test conditions. The bentonite seal was placed 15 cm (6-in) below the topsoil layer. That was about the expected depth of root penetration for the grasses to be planted. The following paragraphs describe the overland flow construction technique. Several construction photographs have been included to more clearly illustrate these techniques. A few recommendations to improve construction have been included in this section, however, more detailed descriptions of operational problems associated with the overland flow earth work plots have been included in a following section of this report.

A bulldozer was used to push the top soil to one side of the site as shown in Figure 3. A few survey stakes were driven and elevations marked to assist the bulldozer operation in grading the site approximately level across the direction of water flow and at a slope of approximately 4% from the top and bottom of the slope. The 4% slope was selected to minimize earth work on the natural site. Prior to any construction, a contour map of the proposed site had been prepared. Using a cut-and-try procedure, the appropriate top and bottom elevations were selected. That established the slope and approximately balanced the cut and fill portions of the site.

A local landscaper using two conventional, rubber-tired, landscaper's tractors, as shown in Figure 4, completed the fine grading. Survey stakes, with two marks as shown in Figure 5, were driven at 15-meter intervals. The lower mark was 8 cm above the required finished elevation of the subsoil, and provided the landscape tractor operators a reference point to uniformly grade the site. The upper mark was located the same distance above the required finished grade of the topsoil, and allowed the operators to fine grade the 15-cm topsoil layer after the bentonite layer was constructed.

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Figure 3. Bulldozer for topsoil removal.

Figure 4. Landscaper's tractors for fine grading.

Figure 5. Surveyor's stake for finished grade location.

The bulldozer was used to transfer the stockpiled topsoil onto the plot, after the bentonite layer was constructed. The fine grading was completed with the landscape tractors using the attachment shown in Figure 6. The side skids were added by the operator to minimize vertical movement of the blade.

A similar earth moving approach would be used on other sites, except no bentonite seal would be required on soil of low permeability. One modification appears warranted. After replacement and fine grading of the topsoil, an evaluation of the water flow pattern over the plot would allow relatively easy modification or regrading of the site. This could be accomplished by applying wastewater and observing the flow pattern. Relatively high and low areas could be easily identified and marked for additional fine grading. Several trials may be necessary, but this would minimize short-circuiting problems after the grass cover developed.

Bentonite Seal

After the subsoil had been fine graded, the bentonite was spread over the plot using the landscape tractor with a broadcast-type seeder, as shown in Figure 7. That provided uniform application, but required about eight trips over the field because the highest rate of application was less than needed. During construction of the lagoons, at that same site, a better method was developed. A wooden square was constructed which enclosed the area to be covered by one bag of bentonite. The bentonite was spread by hand and hand raked to a relatively uniform thickness, as shown in Figure 8.

The landscapers used an attachment to their tractor normally used for scarifing surfaces for seed bed preparation. That unit worked well to mix the bentonite into the soil to form the 5-cm thick seal. Figure 9 shows that unit mixing the bentonite and subsoil. A farm cultipacker was used to compact the mixture before the topsoil was placed above this seal. Considerable care must be taken while replacing the topsoil to assure that the bentonite seal is not distributed.

Grass

The site was not ready for seeding until mid-October which was unusually late for a fall grass planting in that region. Therefore, two seeding procedures were used. First, a drill-type grass seeder attached to the landscaper's tractor was used to plant the seed moving across the plots. Figure 10 shows this operation. The across-plot seeding was used to reduce the possibility of rivulets forming if a rainstorm occured before the grass cover was established.

The second seeding procedure was a hydromulch system using pregerminated seed. Figure 11 shows the application of the hydromulch. The purpose of that second seeding was to add a pregerminated seed to the site and to provide the mulch cover for both improved seed growing conditions and to further protect the site from soil erosion. The seed used was an equal-weight mixture of perennial rye grass and Kentucky 31, a fescue. The total application rate was 40 g/m^2 (8 pounds per 100 square feet).

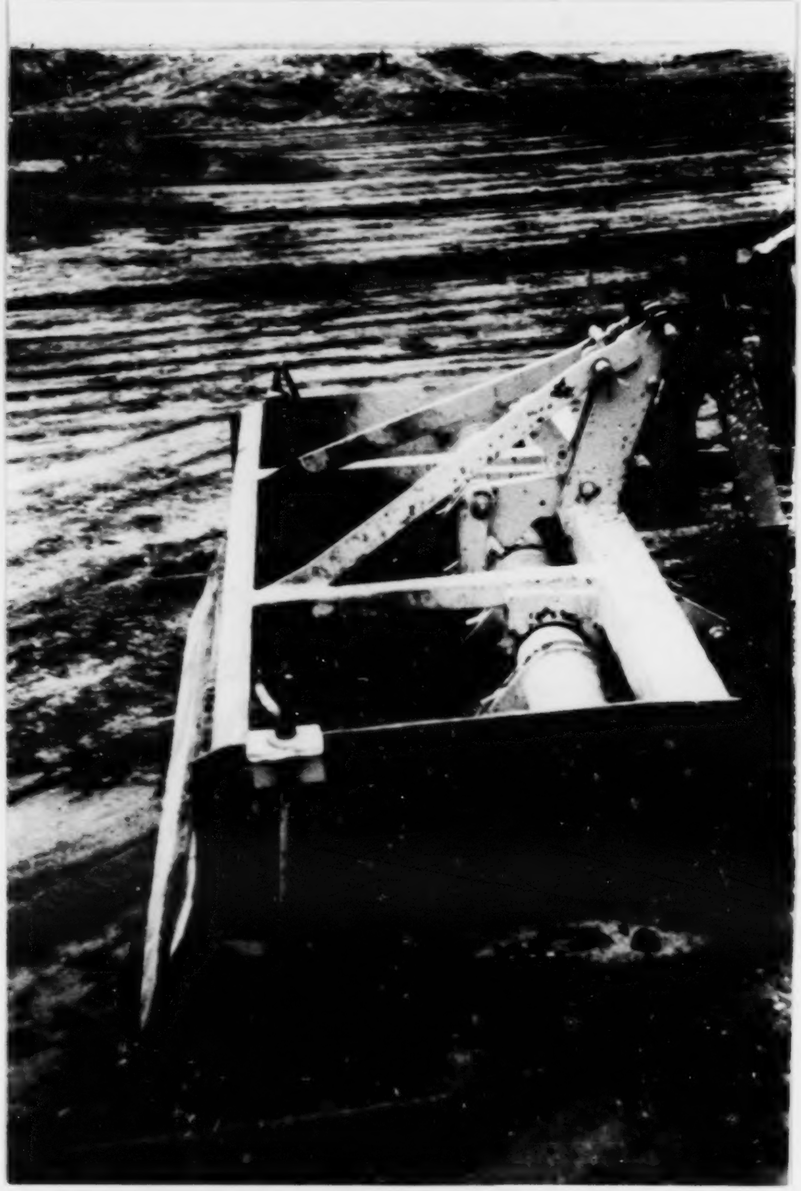

Figure 6. Landscape tractor grader with skids added to improve vertical control.

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Figure 7. Broadcast seeding attachment for bentonite application.

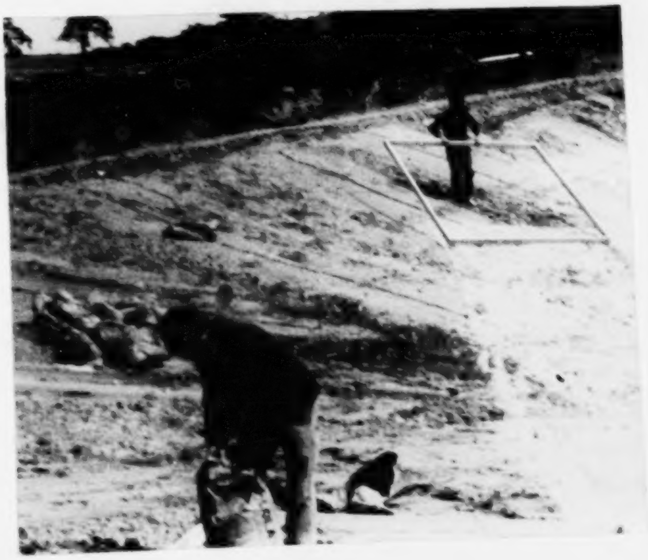


Figure 8. Recommended bentonite application technique.

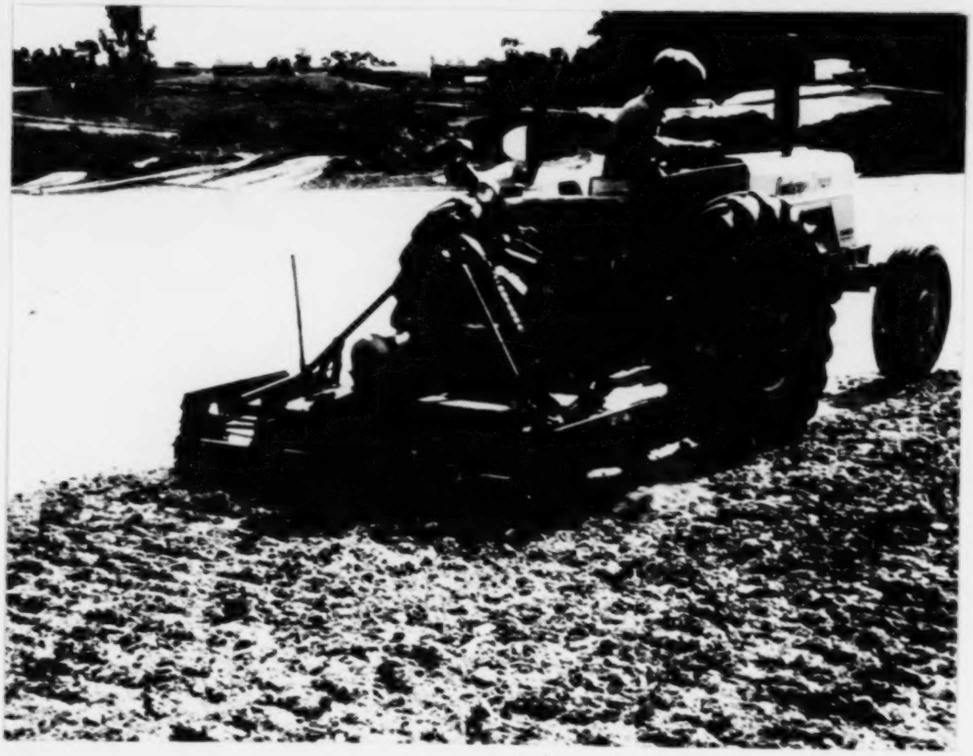


Figure 9. Scarifing attachment shown mixing bentonite and subsoil.

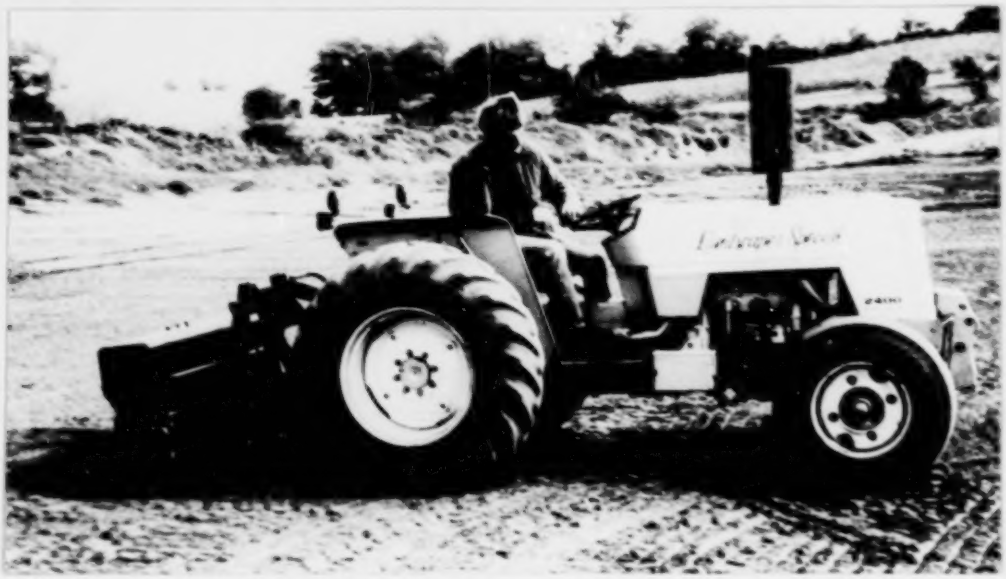


Figure 10. Drill-type grass seeder.

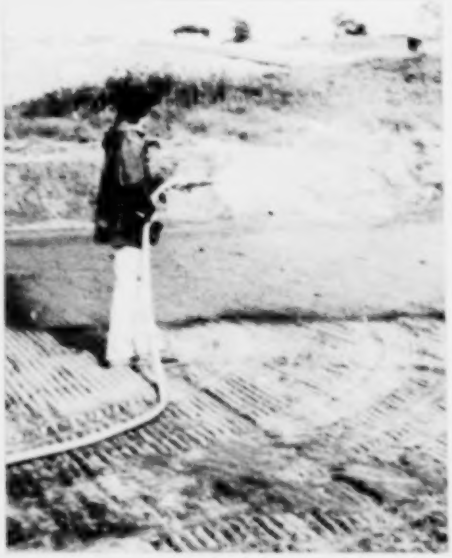
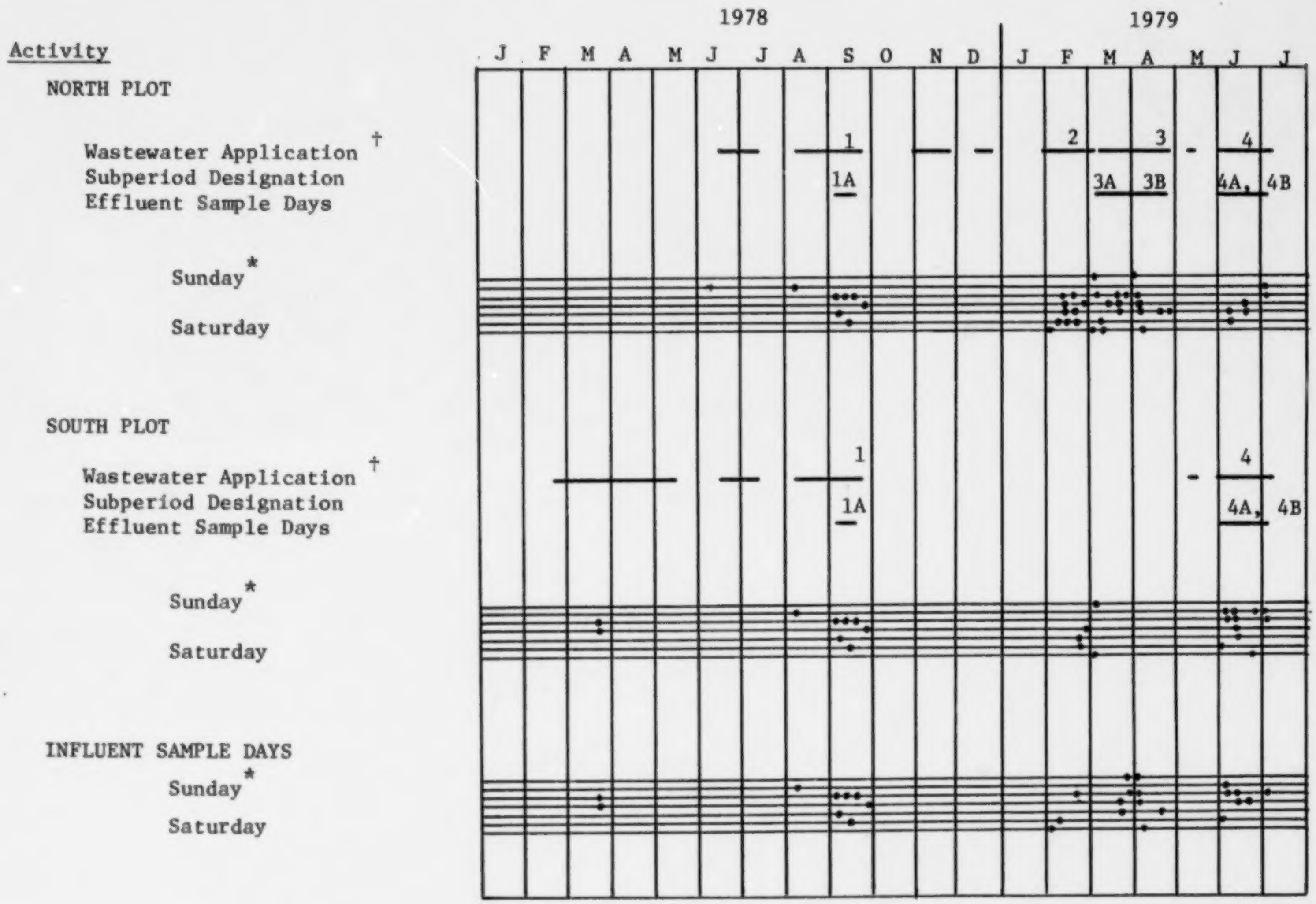


Figure 11. Hydromulch grass seeding.

TABLE 2. APPLICATION AND SAMPLING RECORD



(continued)

In more usual conditions, a single seeding application would be sufficient. The hydromulch has the advantage of easy application and early germination, but local landscapers may provide other suitable seeding services at a more favorable cost. Local personnel of the Soil Conservation Service and local grass seed supplies can assist in selection of suitable grass mixtures which are both water tolerant and grow well locally.

DESIGN AND COST SUMMARY

The overland flow system reported herein was designed according to design procedures presented in the USEPA process design manual "Land Treatment of Municipal Wastewater" (3) with a few modifications. These modifications include the use of the bentonite seal to allow operation in permeable soils; the use of the low pressure wastewater application system; and a different loading cycle. Actual wastewater application rates were also much higher than those used to design the facility. This was due to both higher than anticipated processing plant water use and because the processing plant was in operation during periods when the overland flow site was not operating.

The operating cycle finally selected for that site was one which included 24-hour per day application for 3 to 5 days, followed by a 2 to 3 day drying period. This is discussed in detail in another section of this report. A similar discussion of the low pressure wastewater application system is also included in another section of this report, and design details for the bentonite seal are outlined above.

Aly, et al (4) presented cost estimates in a recent seminar on land treatment. The following paragraphs will complement those costs. The data reported below are most well suited for consideration of small rural, overland flow site construction. The actual costs of this project will be presented below. The work was done during the late summer and fall of 1978, therefore future cost estimates must be adjusted for suitable costs indices.

The total land area of the two plots was 0.31 ha (0.77 acres). They were approximately 79 m long by 20 m wide and located side-by-side. The original site generally sloped in the final direction of wastewater flow, and was located in a valley-like area. The maximum cuts and fills were between one and two meters.

The bulldozer operator was already at the site and had been hired to construct the lagoon. The bulk of the bulldozer work involved stripping and stockpiling the topsoil and rough grading the subsoil to approximately the finished grade. In addition, the bulldozer moved the topsoil back on the site placing it at about the finished grade. The bulldozer and operator costs were:

unit price \$36/hour for 12.5 hours,
for a total of \$450, or \$1450/ha (Bulldozer work).

The two landscaper tractors and operators provided the fine grading of both the subsoil and topsoil layers. The costs associated with fine grading were:

unit price $20/hour for 25 hours,
for a total of $500, or $1610/ha (Landscape tractor work).

In addition, these landscape tractors were used for spreading the bentonite, mixing the bentonite and subsoil, and pulling the cultipacker. The costs associated with bentonite application were:

unit price $20/hour for 12 hours,
for a total of $240, or $770/ha (Bentonite application work).

The bentonite was purchased in bags and in truck load lots (20 tons) directly from the supplier. The cost per load was $1500 ($75/ton). This favorable large quantity unit price was possible because bentonite was also used at the site to seal the lagoons. The costs for bentonite, including both material and shipping, were:

unit price $3.75/bag (100 pounds) for 346 bags,
for a total of $1300, or $4190/ha (Bentonite)

The costs for seeding the site included those associated with drilling the first seeding and the second seeding using the hydromulch system. No substantial part of that cost was due to the actual drilling, because the landscaper tractor used operated at $20 per hour and one or two hours was all that was required. The costs for grass seed and planting were:

$2310 lump sum, or $7450/ha (Grass).

Crushed rock was used under the distributor pipe to minimize erosion and help distribute the water across the site. One truck load (20 tons) was used and the cost was:

$150 lump sum, or $480/ha. (Crushed rock for distributor).

Two grinder pumps (rated at 2 HP each) were used to pump either the processing plant effluent or the lagoon effluent to the overland flow plots. Those two pumps cost $1620. The piping included 670 m (2200 ft) of 3.8-cm (1.5-in.) plastic pipe ($610), 37 m (120 ft) of 10-cm (4-in) plastic pipe ($150), and miscellaneous fittings and materials ($90) to transport and distribute the flow across the top of the overland flow plots. The total material cost for pumping and piping the wastewater to the overland flow plots was:

$2470 lump sum, or $7970 per ha (Pumps and pipe).

The total costs associated with construction of the overland flow plot are summarized in Table 1.

TABLE 1. OVERLAND FLOW PLOT CONSTRUCTION COSTS

	Item	Cost[*]	Cost per hectare
1.	Earth work	$950	$3060
2.	Bentonite seal	1540	4960
3.	Grass	2310	7450
4.	Distributor pipe, pumps and piping [†]	2620	8450
	Total	$7420	$23,920

[*] Based on September 1978 dollars

[†] In addition, labor which was furnished by the farm and processing plant operator, was not accounted for in installation of Item 4 above. An estimate for labor to install Item 4 of approximately 100% of the material costs would increase the overland flow costs to about $10,000 for that site or about $32,000 per hectare.

SECTION 6

EXPERIMENTAL PROCEDURES

EXPERIMENTAL DESIGN

A substantial number of operating problems, which are discussed in a later section, interfered with the operation of the overland flow system. In general, two plots were operated in parallel. The South Plot was placed in operation first, and several months later the North Plot was started. Parallel operation continued for about three months before the South Plot was taken out of service. Finally, during the last two months of the study, both plots were operated in parallel.

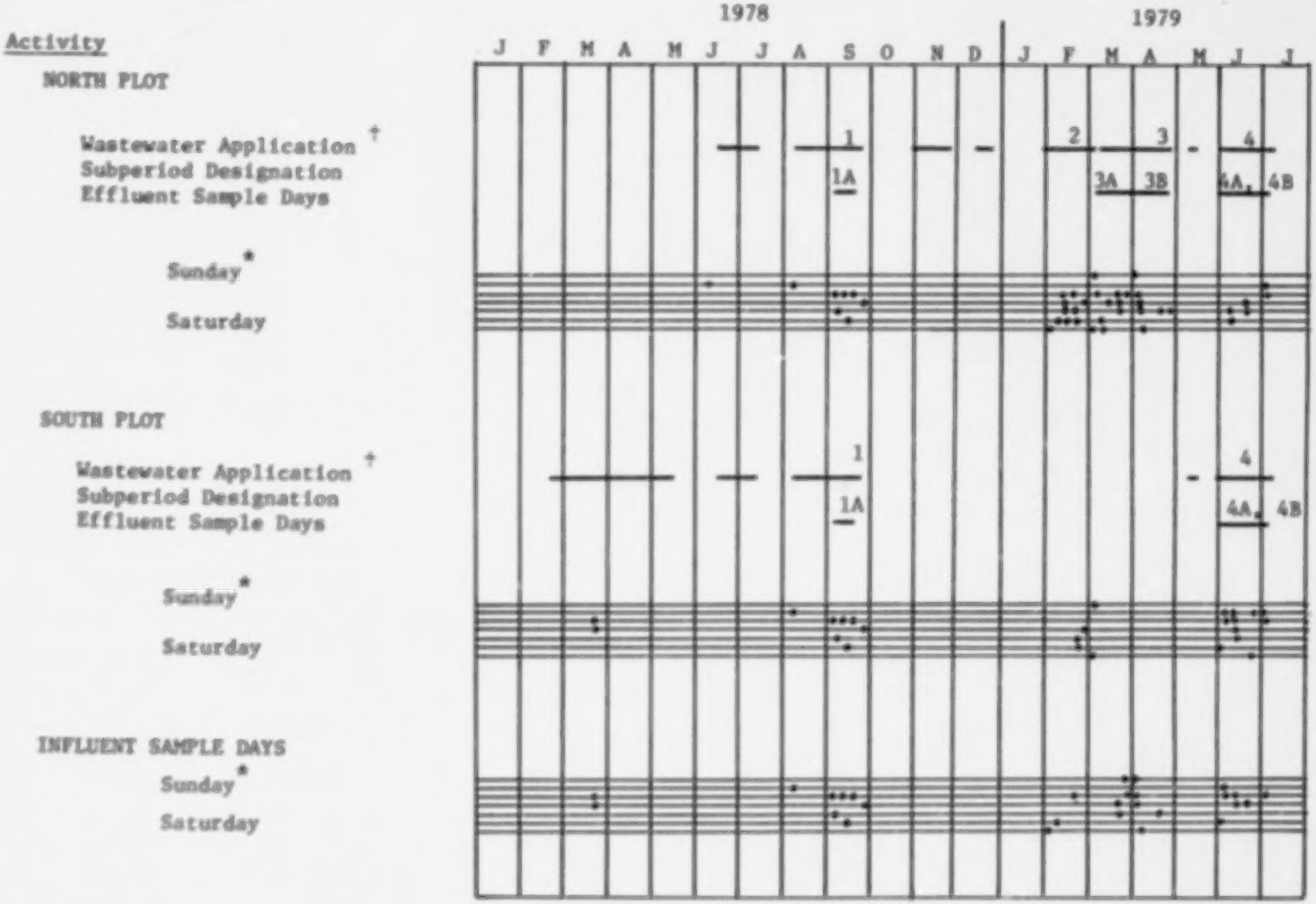
Table 2 shows the periods of time when each plot was in operation. Wastewater application took place in all four seasons, fall, winter, spring and summer. Also included in Table 2 are the dates of overland flow influent and effluent sampling, the monitoring periods, and both the source of the applied wastewater and the method of cycling wastewater application. A more detailed discussion of each overland flow monitoring period has been included in the section headed "Experimental Results."

In addition to the more routine-type monitoring studies described above, several special studies were completed. The routine monitoring study allowed evaluation of overland flow treatment in both warm and cold weather. Those studies considered the effects of weather on BOD_5, suspended solids, nitrogen and phosphorus reduction and water balances at that overland flow site. Special studies were conducted to determine the hydraulic detention time on the overland flow plot, the time required after snow melt before effective overland flow treatment was possible, the quality of snow melt from plots which both had and had not received wastewater during the winter, the degree of treatment received as a function of distance of overland flow, and the effects of high algal concentrations in the overland flow influent.

SAMPLING PROCEDURE ON OVERLAND FLOW PLOTS

Influent and effluent samples were flow-weighted hourly composites representing a four to six hour period. Influent samples were collected from one of the holes in the overland flow distributor pipe. Effluent samples were collected at the overflow of the effluent weir. Samples were collected in 1-ℓ plastic bottles and were stored on ice until the end of the sampling period, and while they were transported to the laboratory.

TABLE 2. APPLICATION AND SAMPLING RECORD



(continued)

TABLE 2 (Continued)

* Dots on the upper and lower lines indicate Sunday and Saturday samples, respectively. The week days have been uniformly spaced between these two.

† Influent to the overland flow plots originated from three different sources. Those have been described in one of the following sections as kill-phase wastewater, wash-phase wastewater (e.g., see Table 4), and lagoon effluent (also see Figure 1). Prior to May 13, 1979, the wastewater source depended on the process plant operation, and was lagoon effluent during non-processing periods. Afterwords, all wastewater passed through the lagoon before overland flow treatment. The major monitoring periods and subperiods, described in detail in Table 6 of a following section, have been shown here for convenience. Three different loading cycles were used. During most application periods, wastewater was applied during the day (8 to 16 hours) and the plots were allowed to rest during the night every day of the week. This resulted in loadings of 9 to 25 cm/week. During August and September, 1978 (Period 1) continuous application was attempted with no drying periods. After May 1, 1979 (Period 4), application was continuous for three to five days, followed by two or three days for drying. That resulted in loadings of 14 to 34 cm/week. Appendix B includes a more detailed description of those loadings.

Some grab samples were collected at various locations along the surface of the overland flow plots. The samples were collected using a 50-mℓ turkey baster. The baster was held at an angle to the water surface to minimize the amount of soil pulled into the baster. That operation was repeated until 1-ℓ had been collected at each sample location. Plastic trays, about 0.5 m^2 in area, were used to support the weight of the individual and prevented leaving foot prints in the wet soil surface. Samples which were to be analyzed for oil and grease, total coliform, or fluorescence were collected separately. Oil and grease samples were composited and were collected in dark glass 1-ℓ bottles and were acidified. Coliform samples were collected as grab samples in autoclaved 250-mℓ glass bottles, and were stored on ice. During the dye study, samples to be analyzed for fluorescence were collected in 50-mℓ test tubes at the effluent drain pipe every five minutes and were analyzed immediately.

FLOW MEASUREMENTS

Influent flow to the overland flow plots was measured at the distributor pipe. One end of the pipe was opened, allowing all water to flow from the pipe at that one point. Water was collected in an 18.9-ℓ (5-gal) bucket and time measurements were made to determine the flow rate.

Signet magnetic flow meters were installed in each influent pipe to the overland flow plot. Those flow meters proved to be difficult to calibrate and keep in calibration, therefore the timed-volume method described above was used.

Effluent flow from each plot was measured using a 22.5° sharp-crest, V-notch weir installed in a sheet metal weir box. An American open channel flow meter was used to indicate and record the total flow. The recorder was checked at least twice each sampling day. Flow from the effluent drain pipe was timed as it filled an 18.9-ℓ (5-gal) bucket. The recorder was reliable and effluent flow measurement problems were not encountered.

Flow rate determinations for the processing plant wastewater were made using a 22.9-cm (9.0-in) sharp-crest, rectangular weir, installed at the overflow of the gravity grease separator. All water discharged from the processing plant passed over the weir. The weir was calibrated when the plant was not in operation by running water at flow of 80 m^3/d (14.7 gpm) and 160 m^3/d (29.4 gpm), and by measuring the stage. For all subsequent stages, measurements were made to the nearest 0.32 cm (0.125 in). That interval was equivalent to about 20 m^3/d (3.7 gpm), thus the accuracy of the measurement was limited to that precision. The weir was used only for special studies and the crest over the weir measured manually at various time intervals.

TEMPERATURE AND WEATHER MEASUREMENTS

Mean daily air temperature values were taken as reported by the National Weather Service at South Bend, Indiana. Soil temperature values were measured using a mercury thermometer, inserted carefully into the soil at the desired depth. A small metal rod was pushed into the soil to make a hole slightly smaller than the thermometer. That allowed inserting the glass thermometer into the soil without breakage. During the winter, the metal rod was also used to measure the depth to frost.

Rainfall, included as influent flow in water balances, was measured using a Texas Electronics, Inc., electric rain gauge transmitter and recorder. The equipment was used during the fourth monitoring period. Earlier rainfall data were obtained from the National Weather Service at South Bend, Indiana.

Pan evaporation data were taken as reported at the Prairie Heights, Indiana station, the closest evaporation data station, located about 25 miles east of the Culver Duck Farm.

ANALYTICAL PROCEDURES

Delivering samples from the field to the laboratory took slightly more than one hour. Nitrogen, COD, BOD_5 and pH analyses were begun immediately and were usually set up within two to four hours after sampling. Phosphorus and suspended solids samples were stored for up to one week. Occasionally, COD and TKN analyses were stored for one or two days after acid additions fixed the results.

Chemical Oxygen Demand

COD tests basically were performed as outlined in Part 508 of Standard

Methods (5). For samples where COD values were less than 100 mg/ℓ, 0.063 N potassium dichromate was used. Greater precision was possible using that normality, rather than the 0.025 N suggested by Standard Methods. Back titration was performed using 0.025 N ferrous ammonium sulfate. Twenty mℓ of sample, or 10 mℓ diluted to 20 mℓ, were used for all tests. Blanks were run in duplicate. The normality of the titrant was checked each time it was used, because of the relative instability of ferrous ammonium sulfate solution. When samples were collected on consecutive days, the sample from the first day was fixed with the sulfuric acid reagent and dichromate solution, and was then sealed with parafilm. On the second day, samples from both days were digested at the same time. Samples were allowed to cool up to 12 hours after digestion, before titration was performed.

Biochemical Oxygen Demand

BOD_5 analyses were performed according to the procedure outlined in Part 507 of Standard Methods (5). Dissolved oxygen (D.O.) was measured using a Yellow Springs Instruments Model 5720A BOD probe, and YSI Model 54A oxygen meter (Part 422F, Standard Methods (5)). The probe included a stirring attachment which allowed measuring the D.O. directly in the BOD bottle.

Total Kjeldahl Nitrogen

TKN digestions were performed according to procedures outlined in Part 421 of Standard Methods (5). The acidimetric ammonia determination was used for analysis of the distillate (Part 418D, Standard Methods (5).

Ammonia Nitrogen

Ammonia nitrogen analyses were made according to the nesslerization method outlined in Part 418B of Standard Methods (5). A Bausch and Lomb Spectronic 20 was used to measure transmittance at a wavelength of 410 nm.

Oxidized Nitrogen

Oxidized nitrogen, the sum of nitrite and nitrate as nitrogen, was measured using Hack Chemical Company reagent powder pillows (6). NitraVer VI nitrate reagent and nitriVer III nitrate reagent were used. Those reagents were used for measuring "low range" oxidized nitrogen, for 1 mg/ℓ or less in an undiluted sample. Measurement of oxidized nitrogen less than 0.2 mg/ℓ was considered unreliable, and was reported simply as "less than 0.2 mg/ℓ". Transmittances of samples were read using a Bausch and Lomb Spectronic 20, at a wavelength of 500 nm.

Phosphorus

Phosphorus was measured as total inorganic phosphorus, using a Technicon Auto Analyzer I. Industrial Method No. 3-68W was used (7).

Oil and Grease

Oil and grease analyses were made according to the partition-gravimetric method, Part 502A of Standard Methods (5).

Fluorescence

Fluorescence was measured using a Turner Model 110 Fluorometer, according to the procedures furnished for the instrument (8).

Suspended Solids

Total filterable residue values (i.e., suspended solids) were determined according to the method outlined in Part 208C of Standard Methods (5).

SECTION 7

WASTEWATER TREATMENT PLANT OPERATION

Many operational problems were encountered during the study. This section reports on those problems, their solutions and recommendations to help others avoid those difficulties using similar systems. Fortunately, those difficulties can be controlled and a substantial portion of those problems would have been avoided if the investigators had been able to keep a treatment plant operator at the site. The personnel involved in the study could not be at the site daily because they were located about 50 miles from the site. The employees of the processing plant, assigned to assist in operating these facilities, also had serious difficulties in startup of the new processing plant and often neglected operation of the waste treatment facilities.

A history of operation on each of the two overland flow plots has been included in Appendix Table B-1. Much of the delays and periods of no operation resulted from pump failure or other operating problems discussed below.

PRETREATMENT PROBLEMNS

National values for the flow and total volume of water needed to process ducks were used as the design basis for wastewater pretreatment facilities. The flow through this new plant was constant, and independent of the number of ducks processed. The number of ducks processed was decreased below optimum by machinery malfunctions, inexperienced personnel, and problems with pin feathers remaining on the ducks. As a result, water use was substantially greater than expected. Water use under the best conditions observed was almost twice the design water use.

The most significant consequence of the excessive water use was overloading of the in-plant pretreatment system, which included a fine screen and a gravity grease separator.

Problem: Wastewater Flow Surges

During normal operation, flow rates through the plant ranged from 350 to 440 m^3/d (65 to 80 gpm). Although that rate was excessive, it did not exceed the capacity of the rotating screen and the gravity separator (550 m^3/d). However, during washdown periods, flow rates often doubled and overloaded the screen and separator.

Solution --

Low pressure hoses were replaced with high pressure hoses. Low pressure hoses delivering up to 80 m^3/d (15 gpm) were in common use during washdown periods. Only experienced personnel used those hoses sparingly. New workers ran them continuously and often left them on after washdowns were completed. The flow rate of the high pressure hoses was only about 20 m^3/d.

Recommendations --

Use of squeegies and shovels for day cleanup were encouraged, but high personnel turnover made that method of flow reduction ineffective.

The practice of emptying high volume tanks was modified by partially covering drain openings. That limited flow to less than 50 m^3/d. Occasionally, that step was ignored, resulting in flows in excess of 750 m^3/d. Installation of valves would be necessary to prevent those incidents.

Problem: Feathers Entering the Wastewater

Wastewater from the processing plant floor drained into open channels. Water from the slaughter room channels passed a rotating screen which separated the bulk of feathers from the wastewater stream. Feathers were removed from the screen with a pitch fork and were placed in a spin dryer. During peak flows, the floor around the screen became flooded. Any feathers on the floor in the area of the spin dryer were then washed into the wastewater stream. These feathers caused problems with the wastewater pumps, as discussed later.

Solution --

A second spin dryer was added (July, 1979) to help keep feathers off the floor.

Recommendations --

Feathers must be removed from the floor throughout the day to prevent clogging of the discharge pipe from the feather room to the pretreatment area.

Elimination of surges in flow, as discussed in the previous section, could help alleviate the problem.

Problem: Offal Washed Directly to the Rotostrainer

In the evisceration room, offal was left on the floor next to open gulleys. During washdown, those solids were washed into the gulley and directly to the fine screen along with the wastewater. Solids not passing the screen were held in a hopper connected to a vacuum line. When the hopper was full, a manual switch was used to turn on the vacuum and empty the hopper. If the manual switch was not used, the hopper overflowed. The offal then fell on the floor and was washed into the gravity separator.

Solution --

No solution of the problem was enacted.

Recommendation --

An automatic switch, possibly weight-activated, should be installed at the hopper to turn on the vacuum. Plant personnel have been unreliable in turning on the vacuum switch.

The practice of washing offal into the gulleys should be stopped, and another effective method of collection should be used. Efforts to convince plant personnel of the importance of this met with little success, mainly due to high personnel turnover.

Offal overflowing of the solids hopper should not be allowed to fall on the floor. A system to catch those solids should be devised.

The design of the floor around the rotostrainer allowed any solids that fell on the floor to be washed into the gravity grease separator. Modification of the design in use in that case would be difficult. The possibility of solids overflowing into the collection hopper should be considered in the design.

Problem: Solids Falling Directly into the Outlet of the Gravity Grease Separator

As originally designed, the top of the gravity separator was open. Being located adjacent to and below the rotostrainer, solids and offal occasionally dropped or would get pushed into the separator outlet, completely by-passing the gravity grease separator.

Solution --

A cover was constructed of sheet metal, and was placed over the separator. The cover was light and could be removed for inspection.

Recommendations --

This method was successful in preventing the problem. The proximity of the hopper and the gravity grease separator outfall was due to lack of space availability for the pretreatment system. This situation should be avoided in future design.

PUMP PROBLEMS

The pumps used to deliver wastewater to the overland flow plots were located in a manhole which received water directly from the pretreatment system. Solids which escaped the pretreatment system caused numerous pump failures between October, 1978 and June, 1979. At least one of the pumps was being repaired during the entire period, and both pumps were out of service for most of December and January. Figure 12 shows the grinder pump removed from the manhole during one of those problems.

Elimination of pretreatment problems discussed in the previous section would also eliminate the problems discussed here.

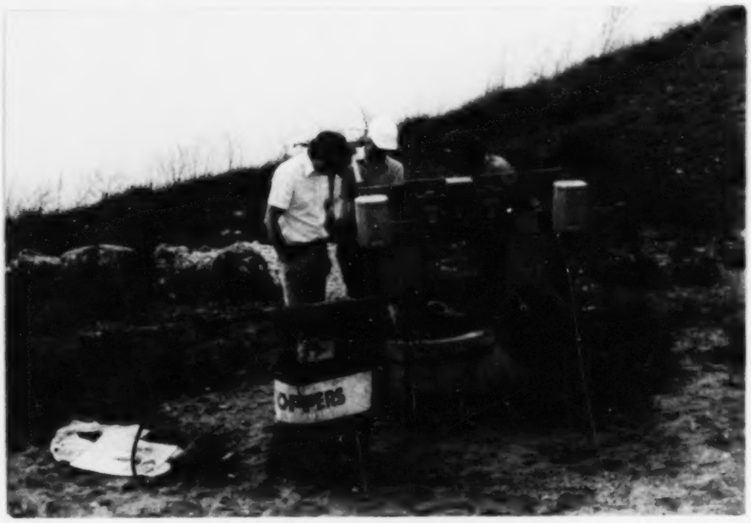


Figure 12. Grinder pump installation.

Problem: Solids at the Bottom of the Manhole Clogging the Pumps

Grit, offal and pieces of feathers which passed the pretreatment system sunk to the bottom of the manhole. After one year of operation, the accumulation of solids covered the 1.8-m floor of the manhole to a depth of approximately 0.5 m. The intake for the grinder pump which delivered wastewater to the overland flow plot was located at that depth. Due to the proximity of the solids, the pumps clogged frequently. The grinder pump was incapable of handling stringy solids, especially feathers, when clumped together with grease.

Solution --

At first it was not apparent that the pump was submerged in the solids at the bottom of the manhole. Each time the pump clogged it was raised from the manhole, disassembled and solids were removed from the discharge opening.

The depth to the grit on the bottom of the manhole was measured using a metal rod. When the measurement showed the proximity of the pumps to the solids, the discharge pump was shortened to raise the pump above the solids.

Recommendations --

In October, 1978 it was suggested that a septic tank pumping truck should be used to clean out the solids. As of July, 1979, this had not been done.

Problem: Floating Grease, Feathers and Other Solids in the Manhole

Low density solids and grease which passed the pretreatment system floated near the top of the manhole. The solids made it difficult to remove the grinder pumps, which hung below the thick mat of grease.

In the summer, the floating solids attracted flies. In addition, some of the solids eventually sunk, increasing the thickness of the solids layer at the bottom of the manhole.

Solution --

In January, 1979, about 2 m^3 of floating solids were removed from the manhole. This was done by two workers: one in the manhole, filling a bucket with solids, and the other above, hoisting the bucket out with a rope. Between January and May, approximately the same volume of floating solids were removed several different times.

Recommendations --

Elimination of pretreatment problems could circumvent this problem.

Problem: Continual Clogging of Pumps

Despite efforts to prevent the pumps from becoming clogged with solids, that problem continued. In May, 1979, one pump clogged and the motor was damaged beyond repair.

Solution --

At that time it was decided to discontinue pumping from the manhole. A cable was suspended across the lagoon between two poles. The cable was attached to a rachet winch at one end, which allowed adjustment of the height of the cable above the water. The pump was attached to a pulley on the cable, and was connected to the underground discharge pipe by a flexible rubber hose. The pump was lowered to a depth of 1 m, which was also 1 m above the lagoon bottom at that location. In that way, stirring up of solids from the bottom was avoided and floating mats of algae and other solids were not pulled into the pump.

Recommendations --

That method of suspending the pumps over the lagoon was easy to construct and operate. Once again, however, the best solution would be to eliminate pretreatment problems, allowing the pumps to remain the manhole. Application of lagoon water led to problems with algae on the overland flow plot, which are described later.

APPLICATION OF WATER TO THE PLOT

Problem: Holes in Distributor Pipe Plugged with Solids

Holes in the distributor pipe were originally directed downward and were 0.6-cm (0.25-in) in diameter. That was to ensure even distribution from each opening. Large solids, especially feathers and grease, frequently plugged many of the holes.

Solutions --

The first solution attempted was daily cleaning of the holes with a wire. After about one month of operation, it became clear that this method would not be satisfactory. It would often be less than one hour before most of the holes were again clogged. Next, the ends of the pipes were cut and replaced with threaded plugs. In that way, solids could be flushed from the distributor pipe by removing the ends. Also, the small holes were sealed and 2.5-cm (1-in) diameter holes were drilled in the side of the pipe. The wastewater and large solids could then overflow the weir-like openings. Because the water no longer flowed from the pipe under pressure, the elevation of the pipe became critical in determining which holes delivered water. To facilitate changes in elevation, cleats were attached to the metal fenceposts which supported the pipe distributor. The pipe was then supported by ropes which were attached to the cleats. The elevation of the pipe could be adjusted by loosening or tightening the rope on the cleat. Figure 13 shows the distributor pipe with these modifications.

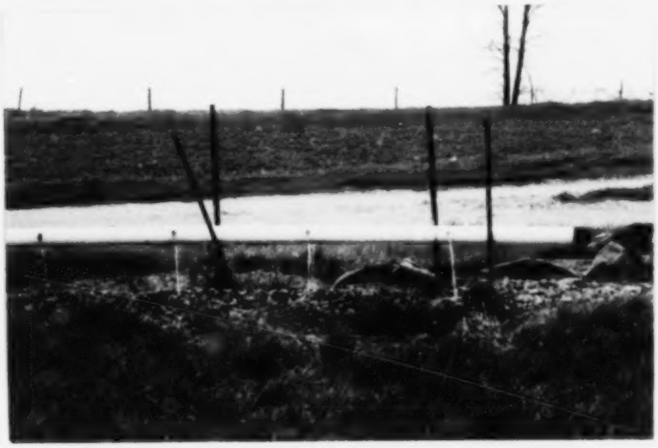


Figure 13. Modified distributor pipe.

There were three major advantages to supporting the pipe with ropes attached to cleats. Flushing the pipe was performed by simply releasing the two ropes near the end being flushed and opening the end plug. The operation required less than five minutes and needed to be done about once each week even with the high settleable solids content of the water. The ease of elevation changes also made it possible to apply water to one section of the field and not others. That helped when distribution difficulties were experienced due to low areas in the plot.

The third major advantage was the ability to slope the pipe toward the center during winter operation. That allowed the pipe to backdrain, preventing freezing of water in the pipe. None of those advantages would have been possible if the distribution pipe had been attached permanently to the ground.

Problem: Wind Blowing Water Applied Away from the Plot

On days with strong easterly winds, water was blown back away from the overland flow plots before it reached the ground. On those days, low lying ground immediatly behind the application point collected water and allowed it to infiltrate.

Solution --

No effort was made to correct that problem.

Recommendations --

Future designs should place the distributor pipe approximately 2-m downhill above the bentonite seal, if the pipe is to be suspended above the ground, and loss of windblows water is to be avoided.

Problem: Penetration of the Bentonite Seal by the Stakes Supporting the Distributor Pipe

Steel fence posts were driven through the bentonite layer to support the distributor pipe. Those holes could contribute to leaks through the seal.

Recommendations --

Increased amounts of bentonite should be used in the area where the posts would be driven during construction. This would improve the seal around the posts.

DISTRIBUTION OF WATER ACROSS THE PLOTS

Problem: Shortcircuiting Caused by Irregular Surface

Erosion of the soil surface, or failure to properly check the surface elevation before crop planting can cause this problem. Shortcircuiting reduces the usable land area, and decreases the hydraulic detention time of the system.

Solutions --

The first solution attempted was construction of a dike perpendicular to the direction of flow, which collected the water and redistributed it. That led to problems caused by ponding of water behind the dikes. The ponding killed the grass cover and allowed algae to grow in the ponded water. Later those dikes were constructed at an angle of approximately 45° or less to the desired downhill direction of flow. The dikes were usually about 15-cm in height and 30-cm in width. Their length varied from about 2-m to 5-m depending on the water flow pattern. Those dikes redirected the water with no appreciable ponding. When placed in the correct location the dikes effectively distributed water throughout the field.

The dikes were constructed or modified soon after the beginning of an application cycle. At that time, the ground was solid, eliminating the problem of leaving footprints on the slope. The water would be redirected as it made its way down the dry slope.

Recommendations --

The dikes proved to be an excellent way to control the direction of water flow and to prevent shortcircuiting.

However, the initial grading of the plot could be checked by applying water to the plot before the grass crop was planted, and by observing water flow patterns. Regrading could then be accomplished and after several trials, the grass could be planted. After the grass cover was established, the dikes could be used effectively to assure nearly complete distribution of the flow.

High pressure spray distribution systems, which apply the wastewater to about one-third of the plot, could overcome some of those problems. Shortcircuiting and excessive hydraulic loadings at the head end of the plot would become less important. Designers may wish to consider this method of application.

The plots were unusually long, 79 m. That resulted in unusually high loading per unit width. For example, plots which are one-half as long, the more usual length, would have only one-half the flow per unit width for an equal surface loading (i.e., cm/m^2). Therefore, shortcircuiting and other undesirable effects associated with high flows at the top of the plot, would be less serious on plots constructed at more conventional lengths.

Problem: Leaks in the Bentonite Seal

Water loss on the South Plot led to the conclusion that there was a leak in the bentonite seal. A large dry area was noted which was not at a higher elevation than surrounding areas. It was assumed that the leak in the seal was in the section directly uphill of that area.

Solution --

A dike was built to prevent water from entering the area of the leak. Water recovery improved considerably, although it was not as high as water recovery for the North Plot.

Recommendations --

The break in the bentonite seal undoubtedly occured when topsoil was replaced over the bentonite layer. Careful supervision of that operation is advised.

COLLECTION OF RUNOFF

A description of the water collection troughs is presented in the section titled Treatment Plant Components. The problems experienced with the collection system were minor and did not interfere with system performance. However, the following observations and suggestions are worthy of mention.

Problem: Breaks in the Seal Near the Collection Trough

The system design called for a connection to be made between the bentonite seal on the slope and the bentonite seal lining the collection trough.

Solution --

The edge of the bentonite seal from the slope was clearly visible in many areas along the trough wall, and the connection was simple in those cases. A bentonite application of three times the suggested rate was used (15 kg/m^2), and was mixed into the sand surrounding the bentonite seal of the slope

In areas where the bentonite seal of the slope could not be located, nothing could be done to assure no leaks. Those areas may have contributed to water losses.

Problem: Mud Washing into the Crushed Rock Covering the Collection Pipe

During an intense rainfall, soil was washed from an area adjacent to the plot into and through the crushed rock, clogging the pipe below.

Solution --

The crushed rock cover was removed from the pipe, and the openings were cleared. The pipe was left uncovered throughout the winter, with no adverse effects.

However, one problem arose when the pipe was uncovered. Water standing in the trough was exposed to sunlight, which encouraged algae growth.

Recommendations --

From the experience of the investigators a water collection system consisting of a sealed grass covered sloping trough would be sufficient. If standing water was eliminated, there would be no need to use crushed rock. The capital cost and construction expense of a perforated pipe drainage system was probably not warranted.

INSECT CONTROL

Problem: Fly Larvae and Flies

During spring and early summer of 1978, many flies were observed at the head of the plot.

Solution --

The application cycle was changed to a continuous application. Alternating wet and dry periods within one day appeared to offer ideal conditions for flies. Continuous saturation followed by longer dry periods eliminated the problem of flies.

Problem: Mosquitoes

Mosquitoes reproduce best in shallow ponded water, especially in water that is high in nitrogen and carbon concentrations. Continuous application of wastewater during the summer and fall of 1978 provided ideal conditions for mosquitos breeding. The small depressions were kept filled by the continuous wastewater application and those small pool areas provided ideal conditions for the mosquitos. No quantification of the problem was attempted, but unusually high numbers of mosquitos were observed during this period.

Solution --

Following a drying period of two weeks in October, no mosquito problems were encountered. That was probably also due to the cooler weather.

A researcher involved in investigation of mosquito control at the University of Notre Dame suggested that 24 hours of dry conditions each week would effectively control mosquito populations on the plot. He also suggested that a saturation period in excess of two or three days would control fly populations. Application cycles which provided both of these conditions were adopted beginning in June, 1979. There were no problems observed with flies or mosquitos after that time.

Recommendations --

That method of mosquito control worked only when the field was allowed to dry. If rain occured during the drying period, extra time was needed. If mosquitos become a serious problem, a week of drying every three or four cycles should sufficiently control the problems.

COLD WEATHER OPERATION

This section covers some of the operational difficulties encountered during the winter of 1978 and 1979. In general, severe cold temperatures increased the frequency of mechanical failure. Operation of the system during cold weather required much more labor than operation during warm weather.

Problem: Frozen Water in the Discharge Pipe

The design of the application system was such that water would drain back through the grinder pumps and into the manhole when the pump was turned off. However, one time the pump discharge clogged with feathers, and the water did not backdrain. After the feathers were removed and the pump was reinstalled, water did not pass through the pipe. It was apparent that water had frozen in the pipe at one or more points.

Solution --

Two sections of pipe were found to be frozen. The first was in the control building, where the pipe came out of the ground and was exposed to air temperatures. An electric heat tape was wrapped around the pipe, and eventually the ice melted. Later, an electric space heater was installed in the building to protect the pipe.

The second frozen section of pipe was at the head of the overland flow plot, where the pipe emerged from the ground. A coupling was disconnected above the frozen section of pipe, and several handfuls of salt were dropped into the pipe. After one day, boiling water was poured down the pipe. The water stood for a few minutes, and eventually broke through. The pipe was cleared of ice and wastewater application was resumed.

Problem: Pump Timer Malfunctions

The timer used to control the grinder pumps was designed for outdoor use, however extremely cold weather (below -15°C) led to frequent malfunctions. The clock and other moving parts were not well protected by the small metal weatherproof box in which they were encased. The timers could not have been moved indoors, as that would have prevented independent control of the two pumps, or would have required substantial additional wiring.

Solution —

No solution to that problem was enacted. Manual operation of the pumps was used during extreme cold.

Recommendation --

Consideration should be given to providing a shelter to enclose the timers, transformers, fuse box and switches for the two pumps. Timers are necessary in small systems, as they are the only realistic way to assure proper application rates in the winter.

GRASS MANAGEMENT

Problem: Grass Killed at Head of Plot

While the overland flow system adequately treated high hydraulic loadings, grass at the head of the plot was not capable of surviving the constantly wet anoxic conditions during the fall-operation period.

The soil also remained saturated during winter operation. Following snowmelt, the grass on a third of the North Plot along the south edge, was dead as shown in Figure 14. Grass on the remainder of the plot was similar in appearance to grass on the South Plot, which had not received wastewater during the winter.

During early spring operation, 14h/d were allowed for the drying of the soil. This proved to be insufficient. After six weeks it was apparent that much of the grass was not recovering as quickly as grass on the South Plot. At that time, more than one-third of the North Plot was covered with a mat of decaying grass, grease, algae and other solids as shown in Figure 15, and the grass grew more in clumps as shown in Figure 16.

Solution --

A solution was chosen which proved successful during the summer operating period. The cycles used previously at the site allowed short daily drying periods. Operation was modified to apply water continuously for three to seven days, followed by a drying period of two or three days. In that way, the plant roots were completely aerated each week. Using this cycle, the grass withstood high hydraulic loadings.

Recommendations --

A more water tolerant grass, such as reed canarygrass, duckweed, or a marsh grass may have been a better choice for the head of the plot. Reed canarygrass was not used at the site due to fear that the grass would spread to adjacent cornfields.

Long drying periods were necessary in the early spring to assist grass growth during that critical period.

Reduced unit width hydraulic loadings, resulting from shorter plots following more conventional design, would also aid the problem as well as aiding the shortcircuiting problem discussed earlier.

Problem: Feathers and Grease Coating the Grass

The large solids passing the pretreatment system and the grinder pump were deposited along the top 20 m of the slope. The high grease content of these solids coated the ground surface and grass roots, choking the

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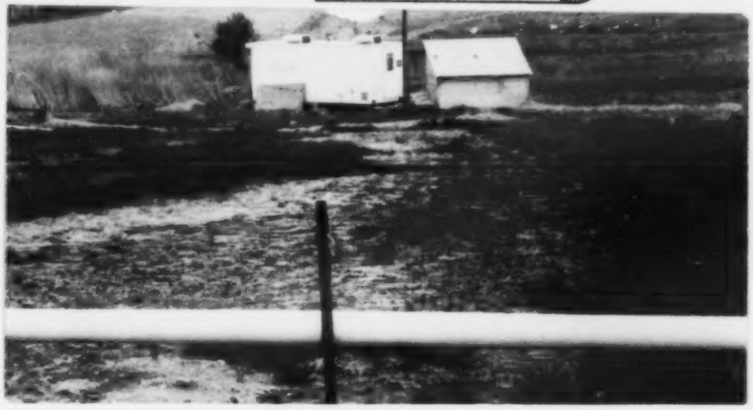


Figure 14. North Plot following winter grass kill.

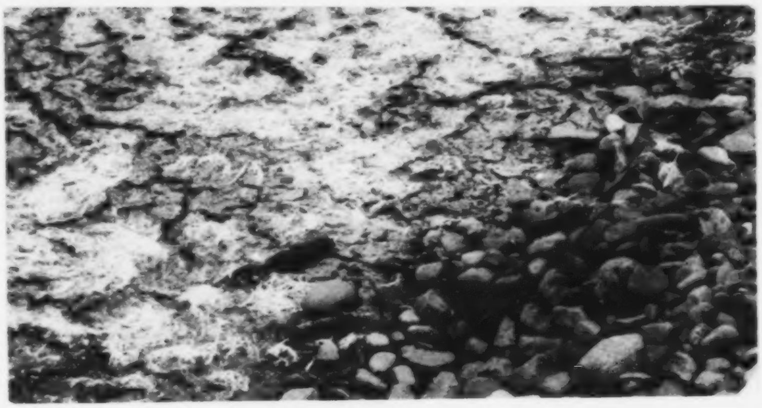


Figure 15. Matting at the top of the North Plot.

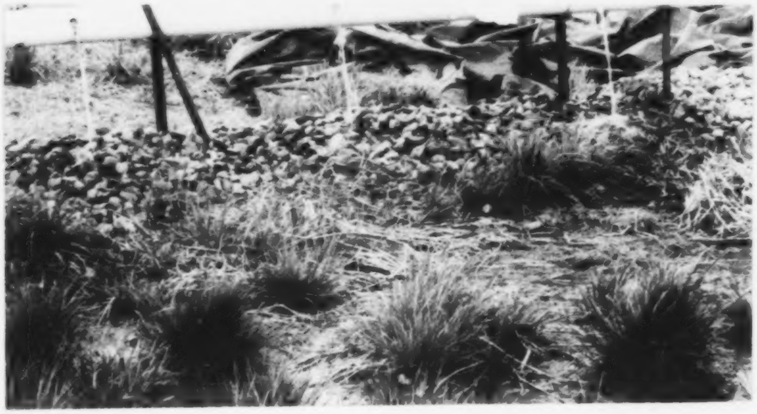


Figure 16. Clumped grass development on the North Plot.

plants. The layer of stones under the distribution pipe clogged with solids. That caused the water applied to flow over the stones, instead of percolating through them as designed.

Solution --

Attempts were made to eliminate the solids, grease and feather problems through in-plant modifications. These met with limited success, as discussed in the pretreatment section.

Recommendations --

A modification which would help eliminate this problem would be the spreading of a layer of stones 3 m to 5 m in width at the point of wastewater application.

The elimination of pretreatment problems would be the most desirable solution.

Problem: Grass Harvesting

The proper grass mowing equipment was not available. Grass was often allowed to grow to a height of about 50 cm, after which it began to fall over, killing grass below. The grass clippings were not completely removed, and resulted in additional grass kill. That allowed water to pass through low-lying bare spots, passing around instead of through the clumps of healthy grass.

Solution --

Shortly after mowing, the grass was hand raked to straighten up the grass and to remove the clippings. That would not be practical on a larger plot.

Recommendations --

A more effective mowing and grass removal approach needs to be developed. Two approaches are possible. First a mower, equippped with a grass catcher, could be used to mow and remove the cut grass in one operation. This would maximize the nutrient removal from the site, but would require more operator time. The alternative would be to cut the grass and process it like a regular hay or silage crop. Because of the sandy soil, the site dried quickly and either method would be effective.

SECTION 8

EXPERIMENTAL RESULTS

This section presents data describing the duck slaughterhouse wastewater, and USEPA proposed guidelines for treatment of this type wastewater.

USEPA proposed guidelines for discharge of BOD_5, suspended solids and ammonia nitrogen are compared with these parameters discharged from the overland flow plots. Loading rates, and influent and effluent concentrations are also presented for these three parameters.

There are no discharge requirements for phosphorus or COD, therefore only average influent and effluent concentrations have been presented. Brief discussions of phosphorus, suspended solids, oil and grease, organic nitrogen and oxidized nitrogen have also been presented.

The emphasis of this study has been on performance of the overland flow plots. Effluent from these plots received further treatment. Effluent during the winter monitoring period, for instance, was returned to the storage lagoon. During other periods, effluent was chemically treated and discharged to the rapid infiltration area. That was particularly effective in removing phosphorus and suspended solids, including algae, from the effluent. Chemical treatment followed by infiltration undoubtedly treated the overland flow effluent sufficiently well to meet USEPA proposed guidelines during all monitoring periods, with the possible exception of the winter period, when effluent concentrations were relatively high.

SLAUGHTERHOUSE WASTEWATER

On February 20, 1979 an intensive investigation of the raw wastewater was conducted. Wastewater was sampled in the slaughterhouse at the overflow weir of the gravity grease separator. Samples were collected and flow was measured every 15 minutes, beginning at the plant start-up (6:00 a.m.) and continuing until final washdown (4:00 p.m.). Wastewater flows and characteristics for 4:00 p.m. to 7:00 p.m. period were estimated based on the results of the similar 3:00 p.m. to 4:00 p.m. period. Figure 17 shows these flow rate variations.

The 15-minute samples were composited, according to flow, for each characteristic phase of the processing operation. For example, four samples collected during washdown of the slaughter area were composited as "slaughter

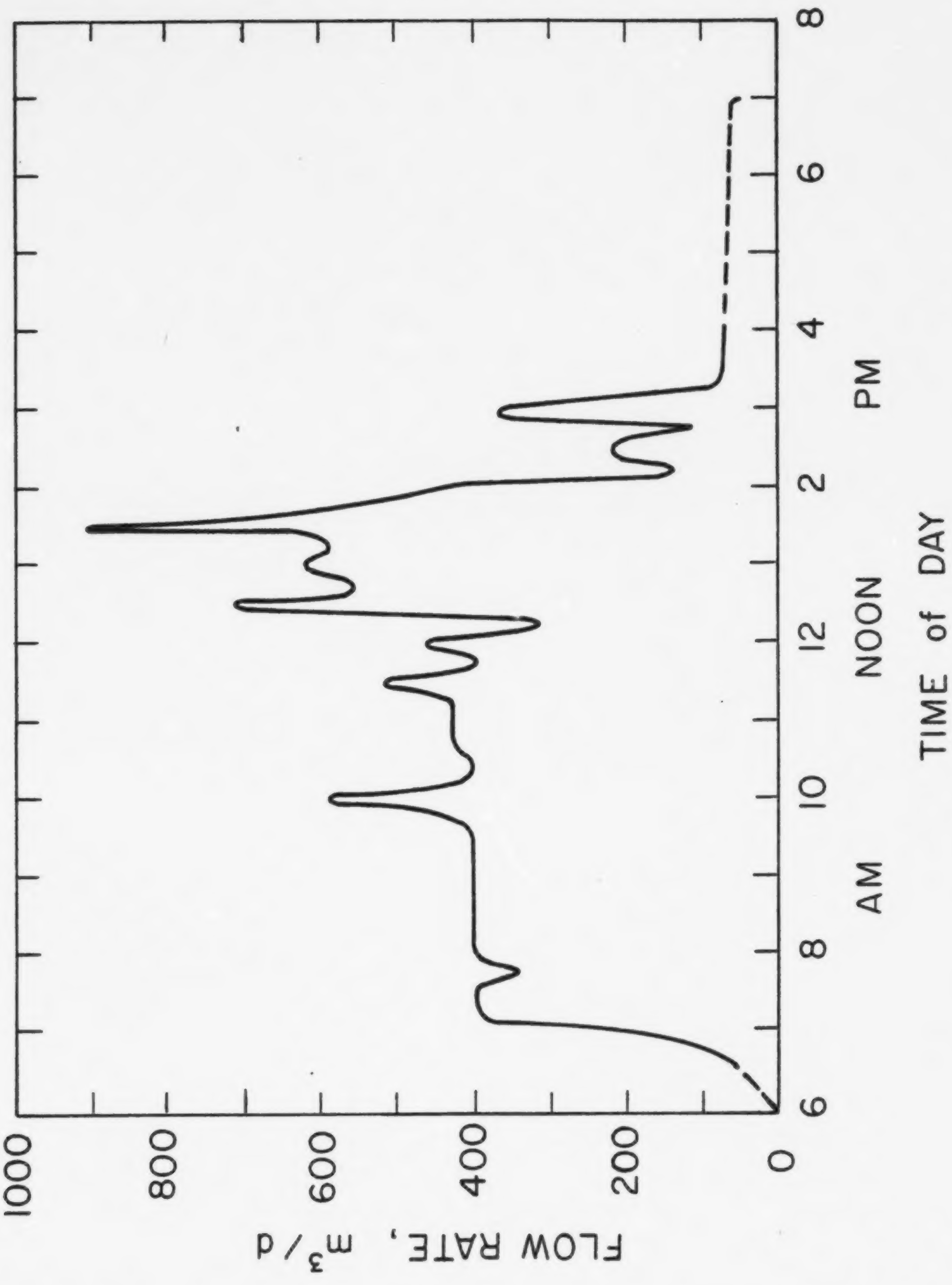


Figure 17. Process plant wastewater flow variations (February 20, 1979)

room wash." The daily operation was broken down into eight phases, as shown in Table 3, and total volume of wastewater and average characteristics are given for each phase.

Later, it was decided that two basic phases were sufficiently representative of the wastewater produced. These two phases were referred to as the "kill phase" and the "wash phase." The kill phase was taken from 6:00 a.m. to 12:00 noon, during which the wastewater color was orange-red. The wash phase was from 12:00 noon to 4:00 p.m. when evisceration, packaging and washing were the major operations. A yellow-orange wastewater with lower BOD_5 and nitrogen but higher phosphorus was produced at that time.

On several days following the study which was reported in Table 3, samples were collected during the two phases discussed above (i.e.,kill phase and wash phase). Using the number of ducks processed and these analyses Table 4 was prepared and shows the quantity of pollutants produced per duck during each phase. Using average quantities for these three days, the total waste production per duck processed is shown in Table 5, where they are compared to the development document survey (9).

Compared to other duck processing plants similarly equipped, these waste quantities are relatively high, and require removal efficiency generally in excess of 90% if the proposed 1983 USEPA discharge guidelines are to be met. These limits, assuming 3 kg of live weight/duck at Culver, are summarized in Table 6.

OVERLAND FLOW WASTEWATER TREATMENT DATA

This report groups the results into four separate monitoring periods: fall, winter, spring and summer. Each period has been further subdivided, as shown in Table 7, for convenience of discussion in subsequent portions of this report. The mean daily temperature, the wastewater application cycle, and hydraulic loading rate for each period also has been shown in Table 7. Table 2, presented in an earlier section, also showed wastewater application and sampling schedules.

All data are included in the Appendix. The following portions summarize these data for each of the monitoring periods.

In general, overland flow influent resulted from one of three sources: these are, raw wastewater during the kill phase, raw wastewater during the wash phase, and lagoon effluent. As can be seen in Appendix A, substantially fewer influent than effluent samples were collected and analyzed. Influent samples collected showed that each of the three sources were relatively consistent. The data in the following sections, therefore, have been presented showing summaries of the influent loadings and effluent loadings. The number of effluent samples has been included in summary tables which follow.

TABLE 3. PROCESSING PLANT WASTEWATER SURVEY
(February 20, 1979)*

Processing operation and time period	Wastewater volume, m^3	BOD_5 mg/ℓ	SS mg/ℓ	TKN mg/ℓ	P mg/ℓ
1. Start-up 6:00 a.m.-7:30 a.m.	10	200	305	14.0	1.2
2. First Slaughter Session 7:30 a.m.-9:15 a.m.	28	485	175	25.5	N.A.
3. Second Slaughter Session 10:15 a.m.-12:00	36	430	160	27.5	2.4
4. Slaughter Room Wash 9:15 a.m.-9:45 a.m. and 12:00 a.m.-1:00 p.m.	18	260	90	16.0	1.2
5. Evisceration Room Scalder and Defeather Tank Discharge 1:00 p.m.-1:30 p.m.	24	365	135	24.5	2.3
6. Evisceration Room Wash 1:30 p.m.-2:30 p.m.	28	515	340	28.0	3.9
7. Packaging Room Wash 2:30 p.m.-3:00 p.m.	14	195	135	14.0	5.4
8. General Plant Clean-Up 3:00 p.m.-7:00 p.m.	11	195	135	10.0	5.4
Total Process Day 6:00 a.m.-7:00 p.m.					
Average Characteristics		375	185	22.5	2.9
Total volume or mass	169 m^3	63 kg	31 kg	3.8 kg	0.5 kg

* 1410 ducks, estimated at 3 kg live weight each, were processed on this day. This is unusually low and would result in abnormally high per duck waste productions, however total flows would be reduced only slightly and little concentration changes would be expected.

TABLE 4. WASTE PRODUCTION PER DUCK

Waste product	Sample date and no. of ducks processed 3-21-79 2270 ducks	3-22-79 2530 ducks	4-4-79 2000 ducks	Average
Kill-phase wastewater				
BOD_5, g/duck	13.3	16.5	14.3	14.7
COD,g/duck	24.4	26.1	19.1	23.2
SS, g/duck	9.9	8.7	12.2	10.3
TKN, g/duck	1.48	1.70	1.65	1.61
Wastewater volume, ℓ/duck	49.3	44.7	53.1	49.0
Wash-phase wastewater				
BOD_5, g/duck	3.1	2.6	4.6	3.4
COD,g/duck	5.1	3.3	6.7	5.0
SS, g/duck	1.6	0.8	4.1	2.2
TKN, g/duck	0.22	0.23	0.43	0.29
Wastewater volume, ℓ/duck	20.0	22.7	21.5	21.4

TABLE 5. WASTE PRODUCTION SUMMARY

Item	Culver plant	EPA survey values*
Wastewater volume,		
ℓ/duck	70.4	74.9
gallons/duck	18.6	19.8
BOD_5, g/duck	18	21
COD, g/duck	28	52
SS, g/duck	12	12
TKN, g/duck	2	4

* Source: Reference 9

TABLE 6. EFFLUENT LIMITATIONS

Item	EPA proposed per live weight killed*	Converted to Culver conditions	
		Per duck†	Effluent concentration#
BOD_5	0.39 g/kg	1.17 g	33 mg/ℓ
COD	no limit	-	-
SS	0.46 g/kg	1.38 g	39 mg/ℓ
Oil and Grease	0.26 g/kg	0.78 g	22 mg/ℓ
NH_3-N	(4 mg/ℓ)	-	(4 mg/ℓ)

* Source: Reference 10.

† Based on an average live weight of 3 kg per duck.

Based on 70 ℓ/duck wastewater volume and the per duck mass production shown. A 50% water volume loss has been assumed for overland flow treatment.

TABLE 7. OVERLAND FLOW MONITORING PERIODS AND GENERAL CONDITIONS

No.	Period name	Dates	Plot in operation*	Schedule	Hydraulic loading (cm/wk)	Mean air temp. (°C)
1	Fall	8/7/78- 9/27/78	N & S1	24 h/d and 7 d/wk	25	21
1A	Fall sampling	9/5/78- 9/19/78	N	same	30	24
			S1	same	20	24
2	Winter	2/3/79- 3/2/79	N	variable †	15	-6
3	Spring	3/3/79- 4/26/79	N	10 h/d and 7 d/wk	16	5
3A	Early spring	3/6/79- 3/31/79	N	same	16	3
3B	Late spring	4/1/79- 4/26/79	N	same	16	8
4	Summer	5/24/79- 7/3/79	N & S2	24 h/d and variable †	21	20
4A	Early summer	5/29/79- 6/17/79	N	same	14	20
			S2	same	29	20
4B	Mid-summer	6/18/79- 7/3/79	N	same	17	21
			S2	same	34	21

*N = North Plot, 0.141 ha; S1 = South Plot, 0.170 ha; S2 = South Plot, 0.087 ha.

† See Appendix B for more detailed application schedule.

Water Balance

The total influent and effluent volumes for each period of operation are presented in Table 8. Discussion of water loss by infiltration and evapotranspiration is presented later, including an explanation of factors contributing to the variation in water recovery from day-to-day and season-to-season.

TABLE 8. SEASONAL WATER BALANCES

Period	Plot	Wastewater applied (m^3)	Precipitation (m^3)	Total influent (m^3)	Effluent (m^3)	Water recovery (%)
1A Fall	N	900	90	990	410	40
2A Winter	N	580	50	630	470	75
3 Spring	N	1700	270	1970	780	40
4 Summer	N	1080	50	1130	500	45
4 Summer	S2	1410	10	1420	520	35

Five-Day Biochemical Oxygen Demand

Average BOD_5 data from the four operating periods are presented in Table 9. Filtered BOD_5 analyses were performed during the fourth period (summer) to illustrate the effect of algae on the total BOD_5. The summer period was divided into two sub-periods to illustrate the increased effluent BOD_5 during algae problem periods (4B).

The BOD_5 discharge requirements placed on duck processing plants are quite strict as was shown in Table 6. An effluent BOD_5 of about 33 mg/ℓ would be necessary at the site. The limitation was exceeded during both winter and mid-summer periods of operation, and would require chemical treatment or rapid infiltration to meet BOD_5 limitations. During the winter period, meeting these limits may not be possible even with this additional treatment.

COD values were also determined for the first three periods and have been summarized in Table 10 for comparison to BOD_5 data.

Nitrogen

Average influent and effluent nitrogen concentrations are presented in Table 11. The data represent total nitrogen, which is the sum of organic, nitrite, nitrate and ammonia nitrogen. The spring period has been divided into two sub-periods showing the decrease in effluent nitrogen. The summer period also has been divided into two sub-periods, showing the effect of algae on effluent nitrogen.

TABLE 9. SEASONAL BIOCHEMICAL OXYGEN DEMAND REMOVALS

Period	Influent Conc. mg/ℓ	Influent Mass loading, kg/ha/d	Effluent Conc. mg/ℓ	Effluent No.samples
1. Fall	340	120	7	8
2. Winter	290	60	135	6
3. Spring	240	60	22	15
4A Early summer	125	60	16	6
4B Mid-summer	125	40	37	8
4 Summer filtered *	50	20	17	4

* Filtered samples were collected to assist in evaluating the effect of high algae concentrations.

TABLE 10. SEASONAL CHEMICAL OXYGEN DEMAND REMOVALS

Period	Influent Conc., mg/ℓ	Influent Mass loading, kg/ha/d	Effluent Conc., mg/ℓ
1. Fall	380	130	25
2. Winter	390	80	240
3. Spring	300	70	60

TABLE 11. SEASONAL TOTAL NITROGEN REMOVALS

Period	Influent		Effluent	
	Conc., mg/ℓ	Mass loading, kg/ha/d	Conc., mg/ℓ	No. samples
1. Fall	25	9	4	9
2. Winter	38	8	54	6
3A. Early spring	20	5	14	6
3B. Late spring	30	7	9	9
4A. Early summer	33	16	6	6
4B. Mid-summer	33	11	11	8

There is no USEPA guideline for discharge of total nitrogen, although there is a limitation on the concentration of ammonia nitrogen which may be discharged (4 mg/ℓ). Effluent mass of total nitrogen discharged was close to the USEPA ammonia nitrogen for all periods except winter.

Oxidized and organic nitrogen in the effluent are discussed briefly in the following sections. Ammonia and total nitrogen removal are discussed in more detail later.

Oxidized Nitrogen

Effluent oxidized (nitrate plus nitrite) nitrogen ranged from less than 0.2 mg/ℓ (the lower limits of the analytical method used) to 3 mg/ℓ. No oxidized nitrogen was observed in any effluent from the winter period. During spring operation oxidized nitrogen was not detected until April 3, 1979, when the effluent concentration was 0.3 mg/ℓ. Nearly all effluent samples from the summer and fall monitoring periods contained greater than 0.2 mg/ℓ.

During fall operation, samples were collected from the surface of the overland flow at one-quarter, one-half and three-quarters of the field length, as well as at the influent and effluent. No oxidized nitrogen was measurable in samples collected at the top one-half of the plot. Of the samples collected at three-quarters of the field length, more than one-half contained measurable amounts of oxidized nitrogen.

Organic Nitrogen

In the first three periods of operation, effluent organic nitrogen averaged

1 mg/ℓ and seemed to be unaffected by variation in influent organic nitrogen. Raw processing wastewater contained more organic nitrogen than lagoon water, but increases in effluent nitrogen did not necessarily accompany application changes from lagoon water to raw processing wastewater. This indicates that effluent organic nitrogen may be in the form of dead soil microbes or metabolic by-products from soil microbes, and not necessarily in the form of untreated wastewater. These sources of organic nitrogen make it unlikely that the effluent organic nitrogen from an overland flow system could be maintained at a concentration lower than 1 mg/ℓ.

During the fourth period of operation, effluent organic nitrogen averaged 5 mg/ℓ. The increase was due to algae in the effluent. Control of algae is necessary to minimize effluent organic nitrogen concentrations.

Mineralization of organic nitrogen to ammonia nitrogen was relatively unaffected by cold temperature and anoxic conditions in February. The nitrogen in the raw slaughterhouse wastewater was mainly organic. Effluent from the overland flow plots, however, seldom contained more than 2 mg/ℓ of organic nitrogen during February. The winter conversion from organic to inorganic was as complete as that observed in warmer months. Similar mineralization of nitrogen in the winter has been reported in the literature (11). Microbial mineralization was relatively unaffected by cold or anoxic conditions.

Mineralization also took place in the storage lagoon, where most nitrogen was inorganic despite the largely organic source. In summer, as algal population increased in the lagoon, organic nitrogen also increased.

Phosphorus

Average phosphorus data for the four periods of operation are presented in Table 12. It is clear from these data that very little removal of phosphorus took place.

TABLE 12. SEASONAL PHOSPHORUS REMOVALS

Period	Influent		Effluent
	Conc., mg/ℓ(P)	Mass loading kg/ha/d	Conc., mg/ℓ(P)
1. Fall	2.5	0.9	2.2
2. Winter	2.8	0.6	2.8
3. Spring	3.1	0.7	2.6
4. Summer	3.1	1.0	2.3

Analysis of the soil at that site indicated that there was little iron or aluminum oxide present in the soil (12). That limited the ability of the soil to adsorb phosphorus during infiltration or overland flow. Precipitation of phosphorus by chemical treatment in the lagoon thus appeared to be the most effective method of phosphorus treatment at that site.

Suspended Solids

Average suspended solids data from three of the four monitoring periods are presented in Table 13. Suspended solids were not measured during the fall, the first monitoring period. The suspended solids limitation, 39 mg/ℓ shown in Table 6, was seldom exceeded following overland flow treatment.

TABLE 13. SEASONAL SUSPENDED SOLIDS REMOVALS

Period	Influent		Effluent	
	Conc., mg/ℓ	Mass loading kg/ha/d	Conc., mg/ℓ	No. samples
2. Winter	150	30	40	4
3. Spring	120	30	15	13
4A Early summer	140	70	12	5
4B Mid-summer	190	60	45	7

Effluent solids consisted mainly of solids from the raw wastewater, algal cells and organic matter and soil from the overland plot surface. Very slight soil erosion occurred in a few areas of the slope but erosion was not a problem. Therefore, the contribution of soil erosion to suspended solids was not substantial.

At other overland flow sites, erosion problems have been reported, and have resulted in a considerable increase in suspended solids during rainstorms. At the site, an increase during peak runoff was noticed on only one occasion. The period of high solids (80 mg/ℓ) occurred during summer operation when high influent algae concentrations were observed. The solids were predominantly green in color, and probably consisted mainly of algae washed from the soil surface.

During peak runoff from melting snow, suspended solids ranged from 10 to 35 mg/ℓ, a range typical of days before and after the snowmelt. Those solids consisted mainly of substances washed from the overland plot, because wastewater was not applied at that time.

During the winter period, suspended solids changed proportionally with oxygen demand. The high solids in the effluent most likely consisted of wastewater solids, because treatment was generally poor at that time.

Suspended solids during the summer period, the highest average concentrations experienced, were due mainly to algal cells. During that period, effluent suspended solids concentrations increased proportionally with effluent flow. For all other periods of operation, suspended solids appeared to vary independently of other parameters.

Oil and Grease

Oil and grease concentrations were measured to determine if the overland flow system alone provided adequate reduction.

Raw wastewater was analyzed once, as a flow-weighted composite of all slaughterhouse operations. Lagoon water was analyzed twice, once during winter and once during summer. The oil and grease concentrations for these three samples were 60 mg/ℓ, 16 mg/ℓ, and 8 mg/ℓ, respectively.

Effluent samples were collected during normal winter operation, during snowmelt, during a peak rainfall, and during summer operation. The average of these four effluent samples was 7 mg/ℓ, with none exceeding 10 mg/ℓ.

Coliform

Total coliform organism counts were made on a few samples collected from the overland flow effluent, as shown in Appendix Tables A-2 and A-3. More frequent sampling was not conducted because the chemical treatment lagoon provided chemical disinfection. Total coliform organism counts were 1000 per 100 mℓ or greater on the overland flow effluent samples.

CHEMICAL TREATMENT LAGOON DATA

The chemical treatment lagoon served two major objectives. First, it provided for control of the overland flow plot effluent. In the event that overland flow treatment was attempted under adverse conditions and effluent quality was poor, the contents of that lagoon could be pumped back to the storage lagoon to allow additional treatment. Normally that lagoon served to provide chemical treatment, in a batch mode, for disinfection and phosphorus, BOD_5 and suspended solids reduction. In that case, the lagoon was allowed to fill, laboratory jar tests were conducted to determine chemical dosage, and the lagoon was treated. After treatment, the supernatant was pumped to the infiltration area for further treatment and disposal.

Complete analyses were made on one batch treatment. Jar tests of a sample taken from the lagoon just prior to treatment indicated the following:

·alum dosages required for nearly maximum phosphorus reduction (as Al)	50 mg/ℓ

- sodium hypochlorite dosage required to achieve at least 2.0 mg/ℓ (Cl_2) residual after 30 minutes. 5 mg/ℓ

The lagoon liquid volume was 190 m^3 and the center depth was 2.5 m at the time of treatment. A small floating mechanical aerator (1 hp) was used to provide mixing. After the lagoon was well mixed, a solution of sodium hypochlorite was pumped in for a period of five minutes, to provide a chlorine dosage of 5 mg/ℓ. Mixing was continued for about 30 minutes before the alum solution was added. One hour was required to complete feeding the alum solution. After an additional ten minutes of mixing, the aerator was turned off and the lagoon contents was allowed to settle for a period of about 1.5 hours before draw off was started.

A small residual-type submersible sump pump was used to pump the chemical solutions into the lagoon. A small diameter garden hose (1/2 in) was attached to the pump and was directed to discharge near the aerator where maximum mixing would occur. A large drum (55 gallons) was used to mix the chemicals with lagoon water to provide a suitable feed solution, and the pump was lowered directly into the drum to pump the chemicals into the lagoon.

Grab samples were taken directly from the lagoon to determine chlorine residuals. Grap samples were also taken from the lagoon during mixing and before chemical addition to determine its characteristics before chemical treatment and settling. After treatment was completed a composited sample was collected from the discharge line as the water was pumped from the lagoon. The suction end of the hose attached to the discharge pump was connected to a float, and was submerged about 30 cm below the surface.

The chlorine residuals, total and free, were both greater than 3 mg/ℓ before the addition of alum (25 minutes after sodium hypochlorite dosage was completed). Just prior to discharging the treated water, about 2.5 hours of total contact time, free and combined chlorine residuals dropped to about 2 mg/ℓ. The wastewater characteristics before and after chemical treatment were as shown in Table 14.

TABLE 14. LAGOON BATCH CHEMICAL TREATMENT

Wastewater characteristics	Lagoon contents; before treatment	Lagoon contents; after treatment
BOD_5, mg/ℓ	38	7
BOD_5, filtered, mg/ℓ	23	7
Turbidity, FTU	n.a.	4
Suspended Solids, mg/ℓ	29	20
Ammonia nitrogen, mg/ℓ as N	7.2	7.0

(Continued)

TABLE 14. (continued)

Wastewater characteristics	Lagoon contents; before treatment	Lagoon contents; after treatment
Nitrite plus nitrate, mg/ℓ as N	0.3	0.1
Total Kjeldahl nitrogen, mg/ℓ as N	12.9	8.5
Total phosphate, mg/ℓ as P	2.8	0.4
Inorganic phosphate, mg/ℓ as P	2.1	0.1
Coliform	n.a.	0
pH	n.a.	6.5

SECTION 9

DISCUSSION OF RESULTS

WATER BALANCES

One objective of this study was to determine the effectiveness of an artificial percolation barrier, which would allow overland flow treatment on a permeable soil. Estimation of percolation rate requires estimation of evapotranspiration water removal. Percolation rates vary due to the effect of variables such as application cycle and temperature. These factors are discussed and percolation rates are estimated.

The relationship between the hydraulic loading rate and percentage water recovery is discussed. The use of effluent flow rate data as an estimate of detention time is presented.

Evapotranspiration

Evapotranspiration was estimated in two ways. The first method involved comparison of day-time and night-time effluent flow rates. That could be performed only when wastewater was applied 24 hours per day, and no rainfall occurred. An observable decrease in day-time effluent flow was attributed to evapotranspiration. The difference between daylight effluent volume and the volume calculated using night-time effluent flow was called the evapotranspiration volume. The assumption was that nighttime evapotranspiration was negligible. This is probably nearly true of transpiration but highly unlikely for evaporation. That assumption made evapotranspiration estimated by that approach lower than actual evapotranspiration.

The second estimation method used pan evaporation data from a nearby weather station and a multiplier to convert to evapotranspiration. That method was used when evapotranspiration could not be estimated in the field. Table B-9 in the Appendix shows a comparison of these two estimates during two periods when both were made.

Variation from day to day in the evapotranspiration to pan evaporation ratio was great. The average during the first period, September, 1978, was 0.50 (i.e., 50%) and during June 1979 it was 0.56. A standard deviation of ±0.25 for both periods of study was observed.

Nighttime evaporation made those evapotranspiration estimates low, thus the multiplier was actually greater than 0.6. A multiplier of 1.0 was used to estimate evapotranspiration from pan evaporation. The large amount of air-water contact during overland flow, and the high transpiration under saturated conditions (i.e., the sand layers above the bentonite seal) and because the area adjacent to the site was usually dry, were the reasons used to justify such a high multiplier. Typically, 0.6 has been used to estimate lake evaporation and is often used as an estimate for overland flow evapotranspiration.

The varying contribution of evapotranspiration in the water balance was due mainly to two factors which will be discussed here. Evapotranspiration varied significantly with weather changes. For example, in September, 1978, the average pan evaporation rate was 3.4 cm/wk. However, weekly rates varied from 2.1 to 5.0 cm/wk. That changed the contribution of evapotranspiration from between 8% and 20% of the applied water.

The second factor affecting the contribution of evapotranspiration to the overall water balance was the hydraulic loading rate. This can be illustrated by comparing the period between April 13 and April 26 with the above mentioned September operation. During the former time period, pan evaporation averaged 2.5 cm/wk, yet water was applied at less than one-half of the hydraulic loading rate used in September. Pan evaporation accounted for 16% of the applied water in April, similar to the evapotranspiration of 14% in September.

The data discussed in the previous paragraphs are presented in Table 15. Hydraulic loading rates and pan evaporations are presented for the four periods of operation.

TABLE 15. PAN EVAPORATION AS PERCENTAGE OF APPLIED WATER

Period	Pan evaporation in cm/wk	Average hydraulic loading rate, cm/wk	%
Fall	3.4	25	14
Winter	not measured*	16	<25
Spring			
Mar 6 - Apr 12	not measured*	16	
Apr 13 - Apr 26	2.5	16	16
Summer			
North Plot	5.2	21	25
South Plot	5.2	32	16

* Pan evaporation data were not measured during winter.

Evapotranspiration is an important contributor to the soil aeration process. The 15-cm layer of topsoil at this overland flow site contained about 5 cm of water when saturated. Evapotranspiration alone could remove that amount of water in a typical week in spring, summer or fall. Acting in conjunction with infiltration and drainage downhill, the drying time was even less. During winter months, slow evaporation and lack of transpiration hindered soil aeration.

The evaporation data were unavailable in winter. A considerable amount of evaporation, and possibly snow sublimation, took place when the warm wastewater was exposed to the cold air. The vapor pressure gradient, caused by differences in air and water temperature, drove the reaction. Using an empirical equation presented by Viessman et al. (13) estimate of this type of evaporation ranges from 0.3 cm/d to 2.0 cm/d. The conditions for the latter rate were wastewater temperature of 20°C and an air temperature of 0°C. The temperatures of the raw wastewater applied at the test site were between 18°C and 25°C. The conditions for evaporation of 0.3 cm/d were a water temperature of 4°C and an air temperature of 0°C.

Evaporation continued until water temperature equaled air temperature. While evaporation took place during application, considerably less would have occurred after application ceased. Thus, evaporation probably did not contribute substantially to drying the soil.

While it was impossible to measure winter evaporation, 25% of the water applied during the winter operation period did not appear in the effluent. A substantial amount of that water may have been lost through evaporation, because loss by infiltration was at a minimum due to the frozen ground surface.

There is no way to conclusively show the effect of evapotranspiration on soil aeration with the data collected. The response of effluent nitrogen and oxygen demand to temperature change may have been linked to evapotranspiration. The increased aeration during drying periods may have contributed to that response, discussed later in this section.

Percolation

Percolation of applied water accounts for loss of substantial amounts of water at most overland flow sites. Soils with infiltration rates of less than 1.4×10^{-4} cm/sec (0.2 in/hour) are considered suitable for overland flow according to the USEPA Process Design Manual for Land Treatment (3). Most of the water applied to a slope of this permeability would be lost to percolation, rather than running off the slope, especially on the unusually long slope used in this study.

One of the goals of this project was to minimize percolation. The natural soils at the site had a permeability greater than that suggested in the USEPA Design Manual, and was equal to 0.02 cm/sec. In order to decrease percolation to acceptable levels, a layer of bentonite clay was placed below the topsoil. If integrity of the seal was maintained, infiltration would have been on the order of 10^{-6} cm/sec through that clay lining.

The percolation rate at the overland flow site could not be measured directly. The rate was determined by performing water volume balances using plot influent and effluent information, and evapotranspiration estimates.

Estimations of the amount of water percolating each day were not constant from day to day. The standard deviation usually ranged between 10% and 20% of the total volume of water lost each day.

That variation can be attributed to a number of sources, including inaccurate measurement of water applied, incomplete distribution of water on the plot, rainfall, and temperature, particularly as those variables affected the depth of saturation in the topsoil.

Water volume applied to the plot was measured inaccurately during the first three monitoring periods. That inaccuracy resulted from the assumption that water was delivered to the plot at a constant rate. Early random measurements indicated that the rate was constant, but more frequent measurement later showed that the rate did vary. The variation could account for a 10% increase or decrease in influent volume on any day. The calculated percolation would be subject to that error.

Incomplete distribution of water on the plot due to shortcircuiting would limit the amounts of area through which downward infiltration could occur. Shortcircuiting would thus increase effluent flow and decrease percolation. During the summer operation period shortcircuiting increased toward the end of the study period. The shortcircuiting problem was alleviated by redirecting the water to dry areas. The calculated percolation rate, which had been decreasing, immediately increased when the water was redirected.

Rainfall had an effect on total daily percolation. Percolation rate was maximum when the soil was saturated. If the rainfall occurred when the soil was not saturated, soil moisture increased, thus increasing hydraulic conductivity. Rainfall occurring when the soil was saturated, however, had little or no effect on hydraulic conductivity and percolation loss.

The effects of temperature on water loss by percolation will be discussed later in this section.

Data used to calculate daily percolation volumes are presented in Appendix Table B-9. From these data, average percolation rates were calculated, and are presented in Table 16. Assuming unit hydraulic gradient, the rates would be equivalent to hydraulic conductivity.

The most accurate percolation rates were calculated when water was applied continuously. During that mode of operation the field was continuously saturated, thus the effect of rainfall was negligible, and there was no decrease in percolation at the end of the daily water application cycle. With a 24-hr application, the coefficient of permeability was 3.2 x 10^{-5} cm/sec for an average daily percolated volume of 40 m^3 from the North Plot.

TABLE 16. PERCOLATION RATES

Dates	Plot*	Percolation flow	Percolation rate		Time of application	Corrected percolation rate †	
		m^3/d	cm/d	cm/sec	h/d	cm/d	cm/sec
2/12-2/22	North	5	0.4	0.4×10^{-5}	10	0.9	1.0×10^{-5}
2/24-3/3	North	15	1.1	1.2×10^{-5}	10	2.5	3.0×10^{-5}
3/7-3/31	North	20	1.4	1.6×10^{-5}	10	3.4	3.9×10^{-5}
4/1-4/25	North	17	1.2	1.4×10^{-5}	10	2.9	3.3×10^{-5}
6/5-6/30	North	40	2.8	3.2×10^{-5}	24	2.8	3.2×10^{-5}
5/29-6/30	South	36	4.1	4.8×10^{-5}	24	4.1	4.8×10^{-5}

* Area of North Plot = 0.141 ha; Area of South Plot = 0.087 ha.
† Assumes percolation period equals wastewater application period.

On days in which water was applied only 10 h/d, percolation rates were estimated by assuming that percolation occured only during wastewater application. That was done using the assumption that hydraulic conductivity, a function of soil moisture, decreased to a negligible value when the field was not saturated. The data in Table 16 show clearly how daily percolation is a function of application cycle. Application for a few hours per day at an increased rate may be an effective method of controlling percolation.

The lowest percolation loss was observed during the winter operation period. The apparent rate was reduced to 0.9 cm/d, most likely due to the frozen ground. It is difficult to explain how any water would percolate when frost was intact. It is possible that the water did not percolate but was, instead, lost through evaporation of warm water exposed to the cold air.

In late February, percolation increased. The increase coincided with the day of the first major snowmelt, February 23, 1979. The percolation rate tripled, reaching 2.5 cm/d. Percolation rates had not reached maximum, possibly due to an incomplete melting of the frost layer, or to the high viscosity of the cold water.

During the spring and summer periods the percolation rate was about 3 cm/d. This was equivalent to about 3 x 10^{-5} cm/sec. That was the maximum percolation rate observed at the site, and was about one-third of the upper permeability limit set for overland flow sites (3).

The overall coefficient of permeability observed was most likely the result of a high rate of percolation occurring through a small portion of the seal. The following examples illustrate the possible size of such a leak.

If the water were to percolate through the leak at the rate attributed to the native sand (10^{-2} cm/sec) the leak would need to be only 5 m^2 in area. Another possibility is that there was a larger area partially mixed with the bentonite clay, which allowed a percolation rate on the order of 10^{-3} cm/sec. At that rate, the volume of water lost could pass through an area of 50 m^2.

Percolation in a small area would support the observation that infiltration is a function of number of hours of application. When an application cycle has ended, water above the leak drains through until the surrounding area is no longer saturated. At that time, the hydraulic conductivity decreases to a negligible value.

Water also may have been lost over the side edges of the clay seal, where it was not possible to build an impervious vertical wall. The cross-section of the sides of the plot had an area of 24 m^2. The magnitude of water which may have been lost through the vertical cross-section depended mainly on the moisture content of the soil at the edges of the seal.

Effect of Air Temperature on Water Recovery

Much of the day-to-day and season-to-season fluctuation in water recovery was related to air temperatures. The effects of temperatures on daily water recovery variation was apparent in numerous instances. Instead of commenting on each instance, a brief summary and occasionally an example of the effects are presented.

The influence of temperatures on daily water balances was most significant in the winter and early spring periods. During winter operation, percolation was virtually stopped by the presence of frozen soil. Water recovery decreased considerably after a thaw period of about one week.

Snow fall precipitation normally did not contribute to runoff on the day it occurred. This caused an apparent decrease in water recovery on a number of days during the winter and early spring periods, because snow fall, as precipitation, was added to influent but contributed nothing to effluent. The presence of this accumulated snow on the plot prevented wastewater from freezing when air temperatures dropped as low as -10°C. Water recovery at those times was nearly complete (i.e., effluent volume nearly equalled influent volume). February 12, 1979, for example, showed an effluent volume of 38 m^3 with an influent volume of 40 m^3, or a 95 percent water recovery. On that day, about 0.5 m of snow cover existed on the field, and the maximum, minimum and average air temperatures were -6°C, -18°C, and -12°C, respectively. However, when air temperature dropped much below -10°C, increased wastewater vaporization combined with freezing of wastewater on the plot led to low water recovery. February 17, 1979 serves as an example of that observation. The snow cover was still about 0.5 m, but the maximum, minimum and average air temperatures had dropped to -2°C, -20°C and -16°C, respectively, and the water recovery dropped to 42%.

In March, when there was no snow cover, wastewater froze when the air temperatures dropped below 0°C, and water recovery was low. Later when air temperatures rose above 0°C, the accumulated ice melted resulting in above average water recovery. Alternating patterns of low effluent flow during freezing weather and high flow during warmer weather were noted throughout the winter and early spring monitoring periods.

During the summer and fall monitoring periods, fluctuation in evaporation and transpiration was the most important temperature related influence on daily water recovery.

Hydraulic Detention Time

A detention time study was performed on September 23, 1978 on the North Plot. Fluorescein dye was added to the influent and the effluent fluorescence measured. The results of the study are presented in Figure 18. The background level was 26 fluorescence units. Mean hydraulic residence time was estimated to be between 3.5 and four hours, or slightly greater than the observed mode.

That study was conducted during a period when wastewater was being applied 24 h/d. The application rate was 71 m^3/d (13 gpm). Effluent flow at the time of the study was 27 m^3/d (5 gpm). That detention time was applicable to treatment near the end of a treatment cycle. At the beginning of the cycle, substantially greater detention time was observed because of the need to fill the void spaces in topsoil above the bentonite seal.

Summary

The project demonstrated the feasibility of using overland treatment on highly permeable soils. The maximum coefficient of permeability was estimated at 3 cm/day, less than one-third of the maximum percolation rate recommended by the USEPA overland flow design guidelines (3). Closer supervision during construction of the bentonite seal, would have improved the integrity of the seal, making possible even lower infiltration, and preventing failure due to large leaks.

During cyclic operation daily percolation decreased to about 1.5 cm/day, due to decreased percolation when the soil was not saturated. That mode of operation was effective in decreasing the loss of wastewater by percolation.

Water recovery on individual days varied considerably due to many factors. Water recovery averaged over a period of several weeks, was probably a more useful indication of performance. Average water recovery during the four monitoring periods ranged from 40% to 75% of the applied water volume. Factors

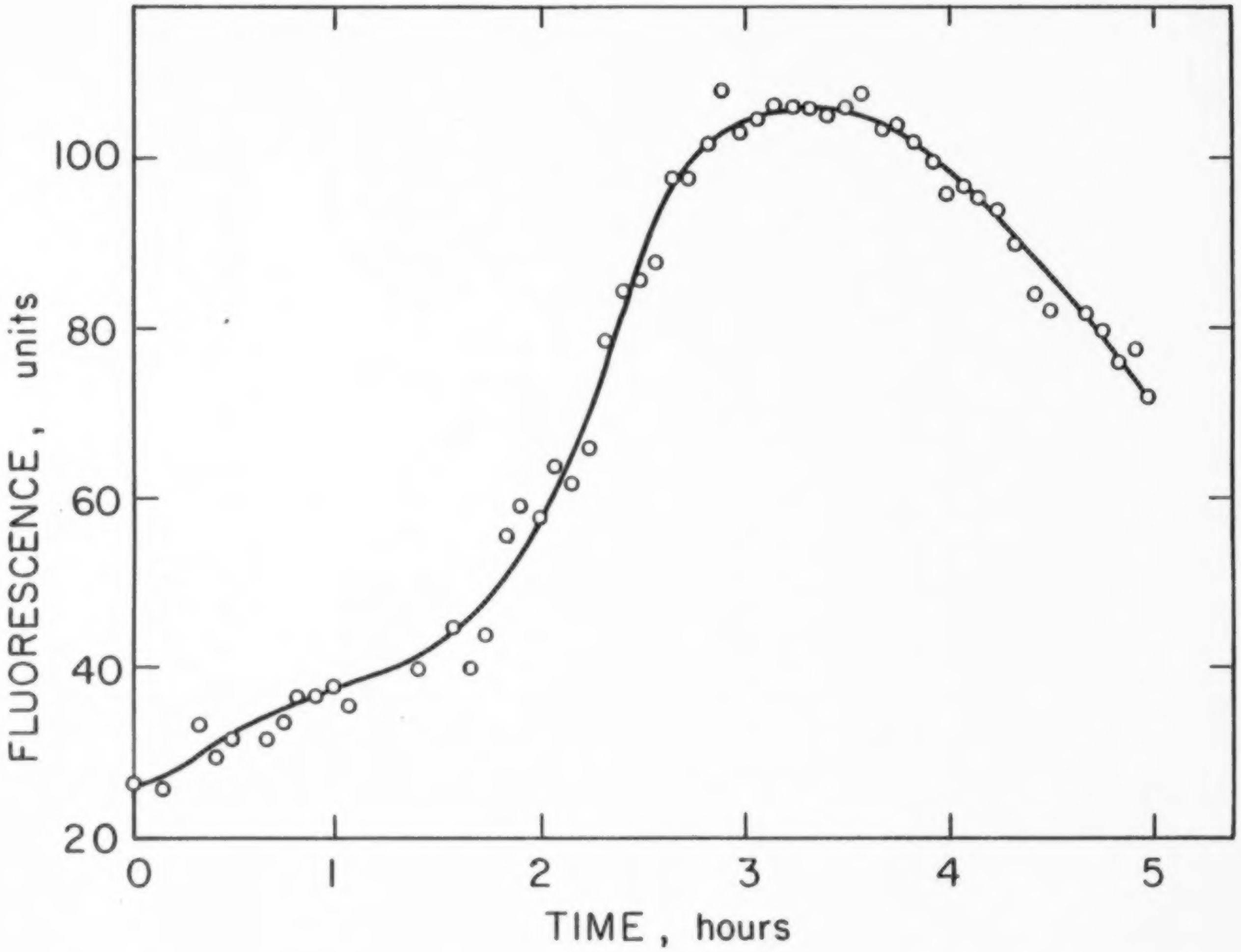


Figure 18. North Plot hydraulic detention time.

contributing to water loss, such as evapotranspiration and percolation, were relatively independent of hydraulic loading rate. Therefore, increased hydraulic loading usually led to increased water recovery.

COLD WEATHER

A primary objective of the project was to report on the operation of an overland flow system in a cold weather region. One intention was to determine the needed winter storage because of decreased loading or complete shutdown of operation.

In this report, cold weather operation refers to the winter and spring monitoring periods. Temperatures averaged -6°C and 5°C for the winter and spring periods, respectively. Soil temperatures appeared to be the most important variable affecting effluent quality. The effect of air temperatures on soil and water temperatures are discussed, for soil both with and without snow cover.

Operation was begun during the coldest month of the year, January, after two months of no operation. No other overland flow system has been "started up" in such adverse conditions. Adaption of a microbial population to those conditions is discussed.

Water quality of snowmelt from a plot which had received no wastewater during the winter was compared with snowmelt from the plot receiving wastewater.

Effect of Snow on Soil and Water Temperature

The relationship between air, soil and water temperatures was of particular interest during the winter and early spring operating periods. During warmer weather, effluent temperatures were usually within about 2°C of air temperatures. In winter and early spring, however, that was not true.

At the beginning of winter wastewater application, the overland flow plot was covered with 0.5 m to 1.0 m of snow. The raw wastewater applied had a temperature of about 20°C, and the lagoon water was about 5°C. Air temperatures did not rise above 0°C during the first three weeks of wastewater application, yet snow melted and the snow cover was lost across the top 15 m of the plot. Water vapor could frequently be seen rising from the upper 10 to 15 m of the plot during application of the warm water. The source of the water vapor may have been a combination of wastewater evaporation and snow sublimation.

Soil temperatures near the point of wastewater application were measured as high as 4°C in the top 5 cm, below which the ground remained frozen. During application of raw wastewater, very little freezing occurred in the exposed area, even when air temperatures were as low as -15°C. At similar air temperatures, a noticeable amount of lagoon water did freeze before reaching the insulating snow cover. Within an hour after the end of application, water froze in the areas not covered by snow.

Water temperatures under the snow were controlled by soil temperatures and melting snow. Beneath the snow cover the top 2 cm of soil maintained a temperature between 0°C and 2°C, apparently independent of fluctuation in air and wastewater temperature. Below that, soil remained frozen. Over the lower one-third of the hill, immediately above the ground, there was a layer of slush varying in depth between 2 and 5 cm. As the wastewater passed through the slush layer, the water temperature dropped. The water did not freeze, however, apparently due to the warmth of the soil below. Measured effluent temperatures were never greater than 1°C, and were typically less than 0.5°C.

After the snow had melted water temperatures once again began to closely follow air temperature fluctuations. Soil temperatures rose accordingly, but at a slower rate. In early April, when air temperature dropped below 0°C for two days, the temperature at a 2-cm depth did not drop below 3°C. Ten m from the top of the plot, the soil temperature at 2 cm was as high at 6°C. (Lagoon water had a temperature of 9°C at that time.) Surface water did not freeze due to the warmth of the soil, but water temperatures dropped to 1°C as they flowed down the plot.

Effluent Oxygen Demand During the Winter Monitoring Period

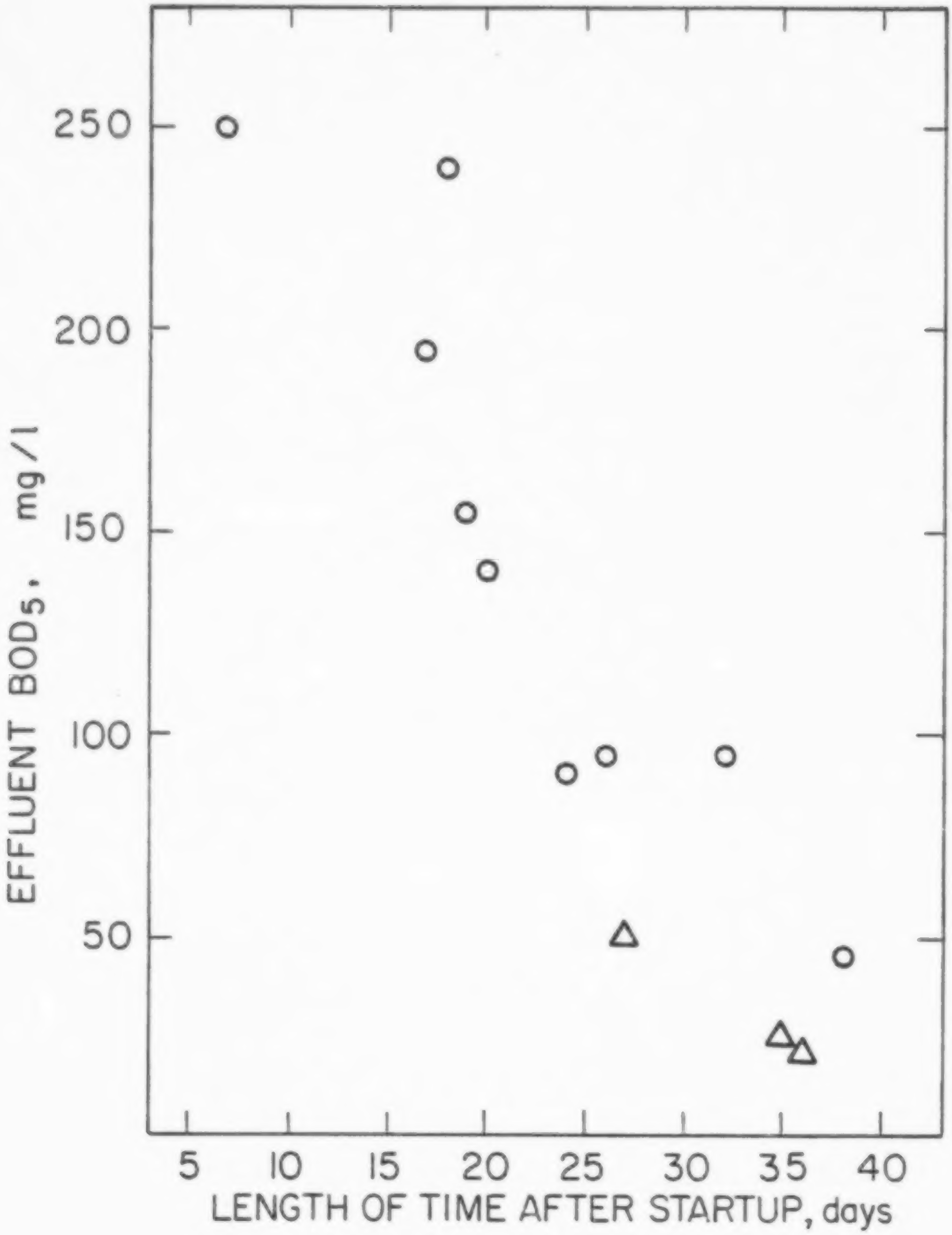
Effluent quality, in terms of BOD_5 and COD, continually improved following the January 28, 1979 start-up. Effluent COD gradually decreased from above 400 mg/ℓ to 195 mg/ℓ, and BOD_5 decreased from 240 mg/ℓ to 95 mg/ℓ during the February 13 to 21, 1979 phase of this period. The mass of BOD_5 in the effluent was 13% of the influent on the last day of that phase, compared to 71% on the first day. These data are presented in the Appendix Table A-2 and are summarized in Figure 19.

Cold temperatures reduced rates, but did not prevent microbial activity. Clusters of what appeared to be white fungi were observed. Those clusters spread throughout the upper 25 m (one-third of the total length) of the plot, where much of the snow cover had melted.

The fungi probably dominated other microbes due to their ability to adapt to the cold temperatures, and their ability to extend hyphae to the water surface to obtain oxygen. Psychrophilic fungi are known to grow and oxidize carbon in temperatures near and lower than 0°C. The soil remained saturated throughout that period in February. Aerobic soil bacteria are most active when the soil is not saturated, allowing oxygen transport into the soil. In the anoxic conditions, only anaeroboc psychrophilic bacteria would be able to compete with the fungi.

The improvement in effluent quality noticed during February was probably indicative of increases in microbial population, and not necessarily due to an increase in oxidation rates of individual microbes. Gradual decrease in effluent oxygen demand is typical during startup of overland flow systems, and is generally attributed to this phenomena.

The gradual increase in air temperatures which took place during that period probably did not affect the effluent oxygen demand. Air temperatures averaged -6°C, but increased above 0°C for one day near the end of the month. The water and soil temperatures were held nearly constant by the overlying snow and warm wastewater. Soil temperatures seldom rose above 1°C when snow cover was present.



Δ designates samples taken during snow melt.

Figure 19. Improvement in effluent BOD_5 with time after winter startup.

Reductions in BOD_5 can occur during winter conditions, especially if snow cover exists and effective treatment precedes those cold weather periods. The BOD_5 reductions probably exceed 75% to 80%.

Effluent Nitrogen During the Winter Monitoring Period

Removal of nitrogen from the wastewater was seriously hindered during winter operation. On the last sample during the phase ending February 28, 1979, effluent nitrogen concentration was more than 80% of that of the influent. Concentration of ammonia in the effluent dropped below 20 mg/ℓ only once during that period, when snow melt dropped the concentration to 13 mg/ℓ.

Effluent nitrogen was greatly affected in the beginning of that period by an ammonia spill which took place in the processing plant on February 1, 1979. Bottled anhydrous ammonia used in the refrigeration system was spilled into the wastewater. Wastewater was being applied to the plot at that time, thus the plot received water containing an ammonium nitrogen concentration estimated to be in excess of 2000 mg/ℓ. On February 3, 1979, two days later, the spill was discovered. Water in the chemical treatment lagoon at the foot of the overland flow plot, which consisted mostly of the effluent from the previous two days, had an ammonia concentration of 2000 mg/ℓ and a pH of 11. Effluent from the plot on February 3, 1979 contained 165 mg/ℓ of ammonia, while influent concentration was less than 50 mg/ℓ.

The decreasing trend in effluent nitrogen during February, shown in Appendix Table A-2, was not indicative of improved treatment, but represented a gradual leaching of ammonia from the plot. Effluent nitrogen remained higher than influent for three weeks following the spill. That indicated that a large amount of ammonia may have been adsorbed in the soil or adsorbed by the snow during the spill, and slowly released over the 3-week period.

A second factor which contributed to the apparent trend of decreasing nitrogen in the effluent was also a result of the ammonia spill. After the ammonia spill effluent had been pumped back to the storage lagoon, the total nitrogen concentration in the lagoon was observed to be 53 mg/ℓ. That high nitrogen concentration was gradually diluted by plant wastewater, which contained between 20 and 40 mg/ℓ of nitrogen. Lagoon water was further diluted when the ice cover melted in late February. Thus influent nitrogen was decreased at about the same rate as effluent nitrogen, with very little improvement in treatment.

The mechanisms of nitrogen removal which may have taken place during that time are not certain. Cellular uptake of nitrogen was perhaps the only method of nitrogen removal. Ammonia volatilization was probably limited by the lack of air replacement under the snow. Nitrification-denitrification was probably limited by the nitrification step. Nitrification had not been observed at temperatures below 2°C, while water temperatures below the snow cover were below that value whenever it was measured. Under continually saturated conditions, which resulted from the cyclic operation providing only about 14 hour/day drying, an anoxic environment probably developed, also preventing nitrification.

Effect of Temperature on Effluent BOD_5

BOD_5 data were studied for any indication of trends showing a relation between air, water or soil temperature and effluent BOD_5. Air temperature data were the most reliable of the data collected, and were reported daily at the South Bend weather station. An attempt to automatically monitor soil temperatures was unsuccessful. Soil and water temperatures were thus measured manually in a random manner.

During the first monitoring period, in August and September, 1978, mean monthly air temperatures were 21°C and 22°C respectively. Mean daily temperatures had a standard deviation of less than 4°C at that time, and had no noticeable direct effect on treatment efficiency.

The snow cover minimized the effect of air temperatures on soil and water temperature during the winter sampling period, February, 1979. Despite rising air temperatures in late February, soil and water temperature did not rise. As air temperature rose, snow melted, keeping water temperatures near 0°C. Soil in contact with the wastewater maintained a similar temperature, minimizing the effect of air temperatures on microbial metabolism.

During the third period of continuous monitoring, there was no snow on the plot. Between March 9 and April 15, the average air temperature was 4°C. The standard deviation of ± 6°C indicated that the air temperatures fluctuated from above freezing to below during that time.

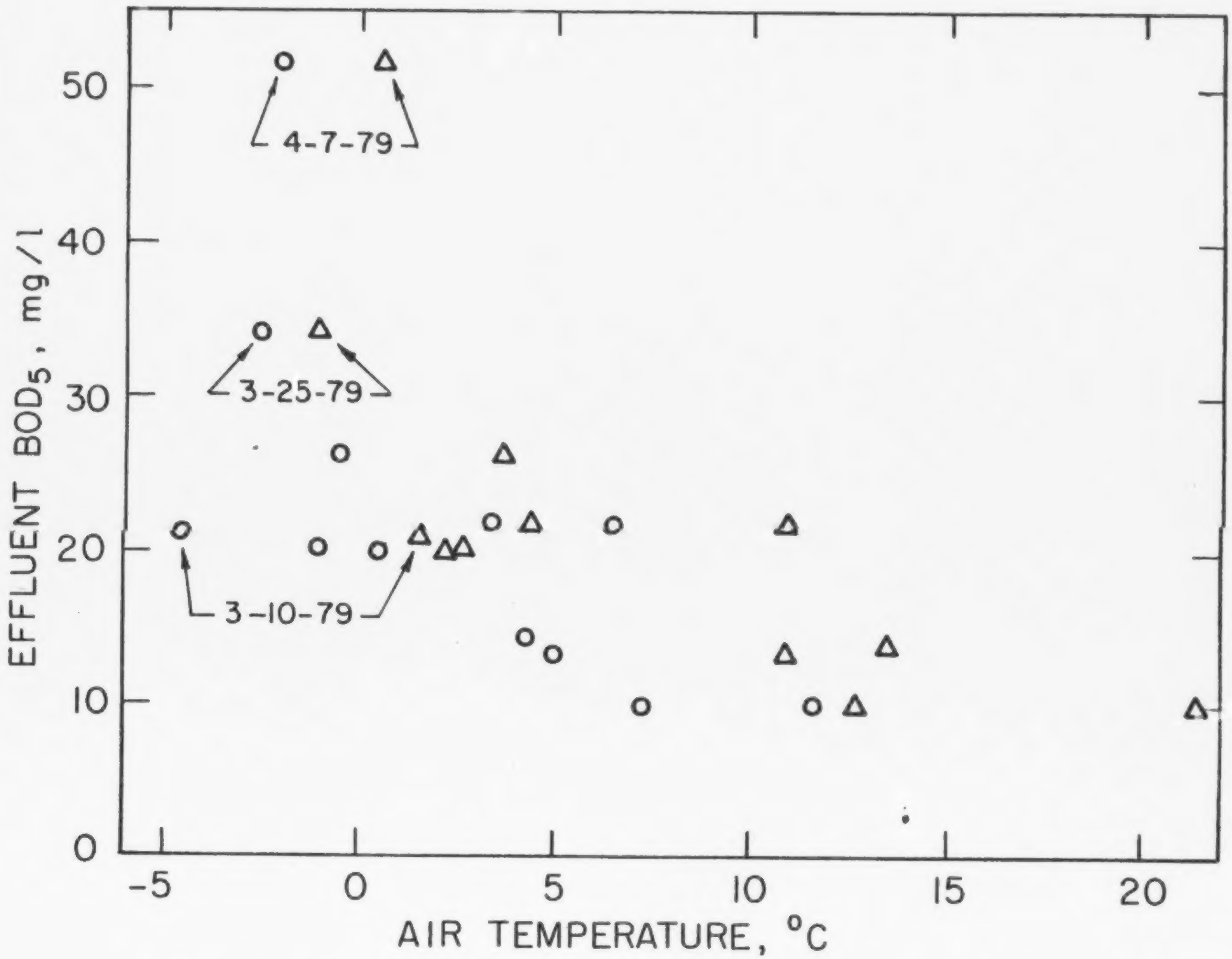
Water and soil temperatures and thus effluent BOD_5 were sensitive to changes in air temperatures. A plot of effluent BOD_5 vs. daily mean and maximum temperatures is shown in Figure 20. This illustrates the manner in which BOD_5 in the effluent increased on cold days and decreased on warmer days.

The relationship between BOD_5 and temperature may be indicative of an increase in biological substrate utilization rate at warmer temperatures. However, that rate cannot be estimated without a knowledge of the hydraulic residence time.

The relationship between temperature and effluent BOD_5 appeared to change during late March and early April. As air temperatures grew warmer, the adverse effect of cold days became progressively more severe. Between March 17 and March 23, minimum air temperatures never fell below 0°C, while average air temperatures were 11°C. After that week, the temperature-BOD_5 relationship appeared to change.

The effect of two cold days, April 6 and 7, illustrated a new sensitivity to temperature fluctuation. On those two days, mean daily temperatures averaged -2°C, with a minimum of -6°C. Effluent BOD_5 on April 7 was 52 mg/ℓ, more than double the BOD_5 of all but one other day during the spring monitoring period (see Figure 20).

The increased sensitivity to cold temperatures after periods of warm temperatures may have been due to a change in the soil microbial population. Mesophilic bacteria and other microbes thriving in moderate temperatures gained



Δ designates maximum daily temperatures. 0 designates mean daily temperatures.

Figure 20. Effluent BOD$_5$ vs. air temperature during the spring period.

ecological advantage during the warm spell in late March. Psychrophilic microbes, which had dominated the population in February and early March would then have been reduced in numbers by inability to compete with the mesophilic microbes. The ability of the mesophilic microbes to grow and metabolize substrate would have been seriously hindered in sub-freezing temperatures. Biederbeck and Campbell reported a similar microbial sensitivity to temperature fluctuations in early spring (14).

The relationship between temperature and BOD_5 was not constant. That was due to the above mentioned dynamic behavior of the microbial population. No mathematical description of the effects of air temperature on BOD_5 removal can be made with the limited information gathered for this report.

During the fourth operating period, summer, air temperature did not appear to affect effluent BOD_5. That period had temperatures similar to that of the first period. Temperature fluctuation of about ± 5°C, apparently did not significantly affect the performance of the overland flow system when the mean air temperature was about 20°C.

That point was illustrated a number of times during the June operation. The best effluent BOD_5, averaging less than 10 mg/ℓ, occurred between June 11, and 14, when air temperatures averaged 20°C. Effluent concentrations above 20 mg/ℓ were common on days when air temperatures were more than 3°C higher than that.

Analysis of the data show that other factors, such as number of days of continuous application, had a more important effect on effluent quality than temperatures during warmer times of the year. Fluctuating temperatures had the greatest effect on BOD_5 when temperatures were near 0°C, and when there was no snow cover.

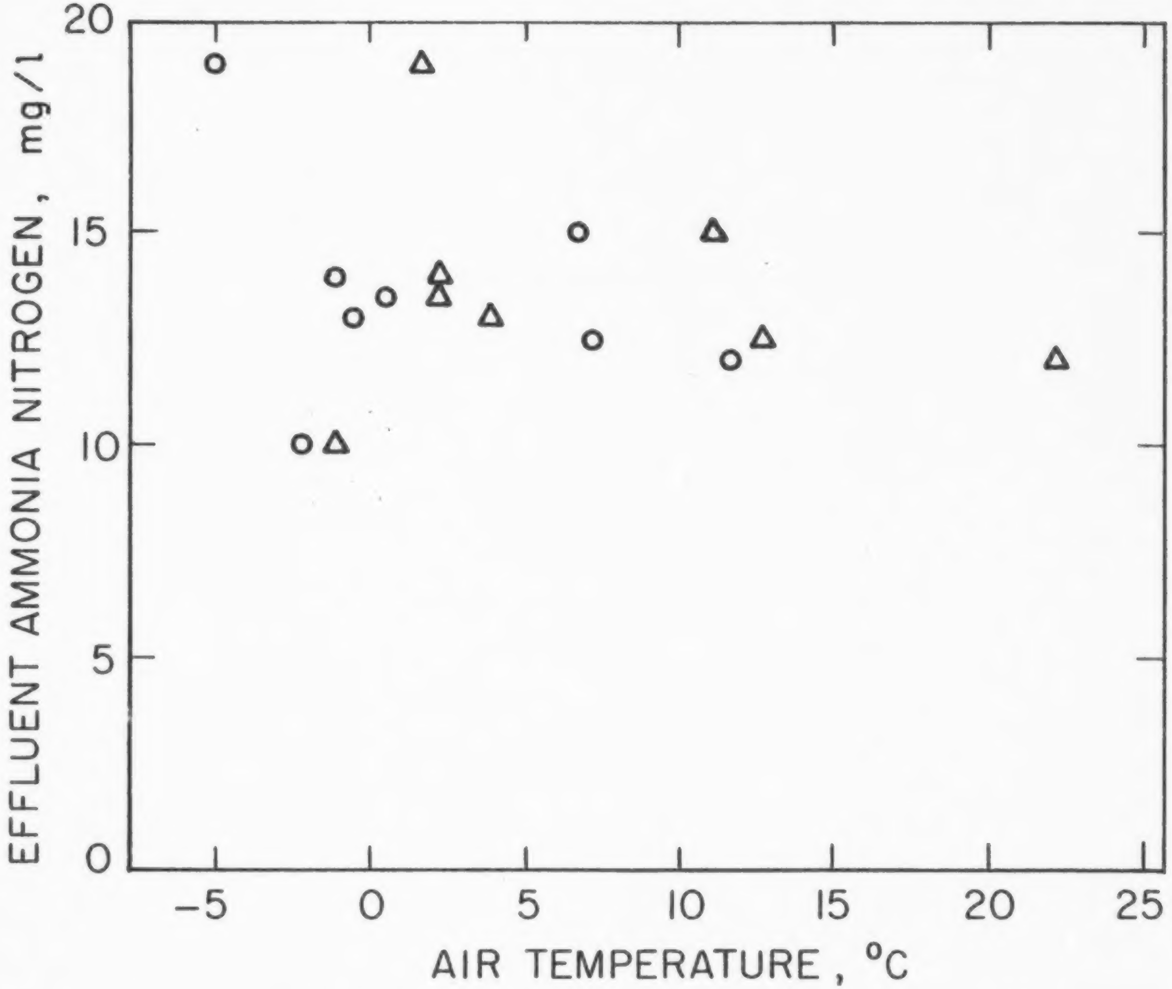
Effect of Temperature on Nitrogen Removal

Effluent nitrogen, much like BOD_5, appeared unaffected by temperature during the fall, summer and winter periods of operation.

Improvement in effluent nitrogen in the early part of the spring period was gradual, and appeared not to respond to the influence of temperature fluctuations. That can be seen in Figure 21. Ammonia nitrogen never decreased below 10 mg/ℓ. At that time, anoxic conditions and possibly low temperatures were limiting the nitrifying bacteria, thus preventing nitrogen removal by denitrification. No nitrate nitrogen was found in the effluent at that time.

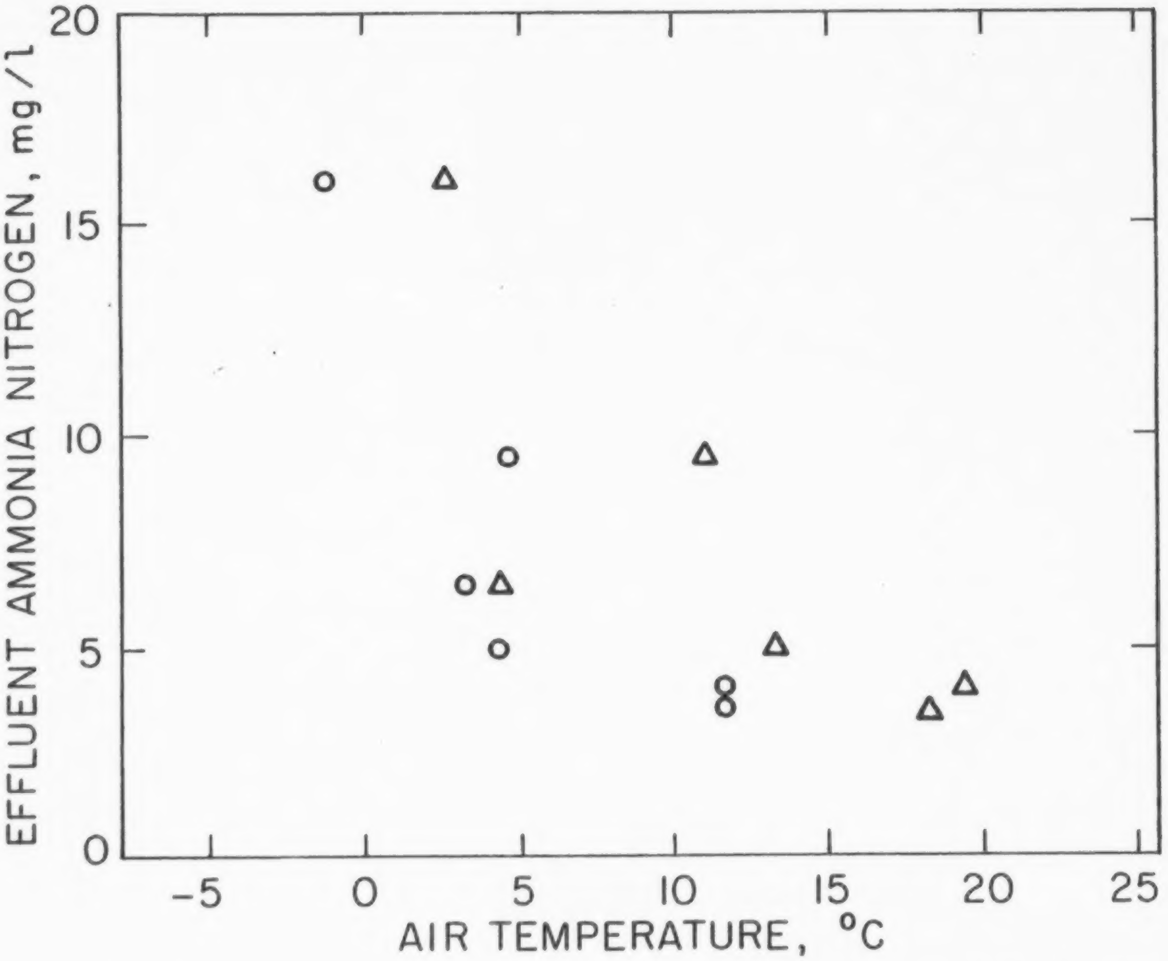
In early April, nitrogen removal began to improve, with concentrations dropping from above 10 mg/ℓ to 5 mg/ℓ. In addition, the nitrate concentration reached measurable levels (greater than 0.2 mg/ℓ) for the first time since the previous fall.

The response to temperature at that time was more significant than in preceding days. That can be seen by comparing Figure 22 to Figure 21. The change in the relation between temperature and nitrogen may be explained by the same reasoning presented in the previous discussion of BOD_5 removal. A



Δ designates maximum daily temperatures. 0 designates mean daily temperatures.

Figure 21. Effluent ammonia nitrogen vs. air temperature during the early spring period.



Δ designates maximum daily temperatures. 0 designates mean daily temperatures.

Figure 22. Effluent ammonia nitrogen vs. air temperature during the late spring period.

change in the microbial population likely took place at this time, favoring nitrifying bacteria.

A sharp drop in temperature to a daily mean of -2°C on April 6 and 7, 1979 caused effluent nitrogen to rise from 5 mg/ℓ to 16 mg/ℓ, with no nitrate present.

Effluent ammonia nitrogen met the USEPA 1983 proposed guideline of 4 mg/ℓ on the last two sampling days in the spring (April 19 and 26, 1979). Mean air temperatures on both of these days were 12°C.

Quality of Snow-Melt Runoff

The first instance of substantial snow melt occurred on February 23, 1979. The equivalent of 18 m^3 of rain (1.27 cm) fell on the North Plot on that day, and 20 m^3 of rain fell on the South Plot. No wastewater was applied on that day.

Effluent flow from the South Plot was greater than that from the North Plot, 85 m^3 compared to 46 m^3. The higher effluent from the South Plot was probably because the snow from the North Plot had melted earlier during application of warm wastewater. That decreased the amount of snow on the plot, minimizing the peak in runoff on that day. No significant runoff had occurred from the South Plot since the first snowfall in November, 1978, thus there was more snow on the plot.

Runoff from the two plots was similar in quality. That was unexpected, as wastewater had not been applied to the South Plot since September, 1978. Suspended solids (10 mg/ℓ) and BOD_5 (50 mg/ℓ) were the same in snow melt from both plots. Ammonia from the North Plot was higher (13 mg/ℓ) but the concentration of the runoff from the South Plot (7.5 mg/ℓ) indicated that ammonia adsorbed from the ammonia spill during the previous fall may have been desorbed into the overlying snow, or leached from the soil by the runoff.

The second and final snowmelt occurred on March 3 and 4, 1979. Temperatures remained above 5°C for over 48 hours, while 3.2 cm of rain fell. At the end of that period, no snow remained on either plot.

The volume of runoff from the North Plot during snowmelt was 209 m^3, of which 63 m^3 was rain, and 33 m^3 was applied wastewater. As much as 20 m^3/d may have infiltrated on March 3 and 4, 1979, assuming that the impervious frost layer was melted. This estimated indicated that between 110 and 150 m^3 water which left the North Plot may have been attributed to snow melt. That is equivalent to approximately 8 to 11 cm of water over the plot area.

The total runoff volume from the South Plot was not measured because a portion of it by-passed the weir box. The by-passed volume was estimated to be about 100 m^3. Another 175 m^3 passed through the weir box, and was measured.

The quality of effluent during the second snowmelt period once again showed that there was little difference between the plot receiving wastewater and the plot not receiving wastewater. The South Plot actually had a higher BOD_5, COD and suspended solids than the North Plot.

The total mass of each constituent washed from the two overland flow plots, during each spring 1979 snowmelt day, is presented in Table 17. The total mass of runoff was similar for each constituent. In all cases, the runoff mass was less than the total mass which would have been applied in 3 cm of the wastewaters usually applied to the plot.

TABLE 17. EFFLUENT CHARACTERISTICS DURING SNOWMELT

		Effluent concentration (mg/ℓ)			Total mass
		Feb. 23	Mar. 3	Mar. 4	(kg/ha)
BOD_5	North Plot*	50	25	<20	45
	South Plot †	50	50	<30	45
COD	North Plot	80	55	48	90
	South Plot	70	70	56	65
SS	North Plot	10	35	n.a.	40
	South Plot	10	20	n.a.	15
NH_3-N	North Plot	13	6.6	6.3	12
	South Plot	7.5	5.3	6.1	6
TKN-N	North Plot	15	n.a.	8.2	15
	South Plot	8.8	n.a.	7.0	8
P_{total}	North Plot	n.a.	1.6	1.9	3
	South Plot	n.a.	1.0	1.0	1

* North Plot: area - 0.14 ha; effluent volume - 210 m^3; wastewater applied during the winter period.

† South Plot: area - 0.17 ha; effluent volume = 175 m^3; wastewater was not applied during the winter period.

Effluent characteristics were studied for one day when wastewater was applied during high flow snowmelt runoff. Effluent runoff volume on March 3 was more than three times that applied, thus the influent was diluted to at least three times its original volume. Detention time on the plot was less than normal, as effluent flow rate was about ten times greater than average. Effluent quality on the day that wastewater was applied was the same as effluent quality the next day, after application had ceased. That indicated that some treatment must have taken place, in addition to dilution.

The total mass of BOD_5 in the effluent on March 3 was less than one-half of the mass applied. The mass of ammonia nitrogen, suspended solids and phosphorus in runoff was about equal to that applied. It should be emphasized that much of the mass of those constituents in the effluent was contributed by the melting snow, indicating substantial reduction in the mass of constituents applied.

Summary

An active microbial population developed on the overland flow site under severe winter conditions. Effluent BOD_5, suspended solids and ammonia concentrations continually improved throughout the winter monitoring period, although wastewater treatment was incomplete. Interruption of wastewater application in December and January due to mechanical problems had an adverse effect on the microbial population. Hydraulic loading was also relatively high (15 cm/wk), which also may have affected treatment adversely.

When temperatures were below 0°C, successful overland flow treatment was not possible without careful operation, maintenance and monitoring. If that was not possible, storage would be required for the months of December, January and February in northern Indiana. Given the required attention, it is still not certain that adequate wastewater treatment can be provided.

Immediate improvement in effluent quality, with respect to BOD_5 and suspended solids was observed following the spring thaw. Ammonia nitrogen treatment was inadequate in March, when air temperatures averaged 3°C. Drying periods of 14 h/d were not sufficient to provide soil aeration during that time. Drying periods of 48 hours or longer would aid the nitrifying bacteria population, as well as crop development.

In mid-April, when air temperatures averaged 10°C, effluent BOD_5 averaged 20 mg/ℓ and effluent ammonia nitrogen was less than 4 mg/ℓ. Drying periods of 14 h/d were adequate for nitrification under those conditions. However, the crop cover was adversely affected by continuous soil saturation.

If winter operation is not going to be attempted, it may be advisable to begin spring operation before snowmelt. That would ensure development of an adequate microbial population before spring treatment would begin and would reduce the total storage time. Effluent from that "start-up" period probably will need to be returned to the storage lagoon for further treatment. Alternatively, low application rates, producing little or no effluent, may be used after the spring thaw to acclimate the system.

Application of wastewater should stop during sudden cold spells in early spring. Temperature drops lead to death or sporulation of soil bacteria, and to a decrease in treatment efficiency.

Snowmelt water carried a large quantity of BOD_5, suspended solids and ammonia. There was little difference in snowmelt characteristics between the plot which had received wastewater during the winter and that which had not.

WARM WEATHER WASTEWATER TREATMENT

In this report, warm weather operation refers to the fall and summer monitoring periods, when average air temperatures were above 20°C. As mentioned in the discussion of cold weather data, temperature fluctuations did not significantly affect effluent quality during warm weather. Trends noticed during those periods of operation were sufficiently different from those noticed during winter and spring operation to warrant separation.

Hydraulic and mass loadings varied throughout those periods. While any direct relationship between those parameters and effluent quality was difficult to develop, some observations of the effects of loading variation are presented. The effects of detention time, using effluent flow as an indicator, are presented. In the final part of this section, the effects of warm weather algal growth are discussed.

BOD_5 and Nitrogen Removal with Distance of Overland Flow

During the fall monitoring period, samples were collected at four different distances downhill from the point of wastewater application: 20 m, 40 m, 60 m and 80 m. The sample which was taken 80 m from the point of application was plot effluent. Each of the other samples was a composite of a number of samples collected at the respective distances from the point of application.

All samples were taken during application of raw slaughterhouse wastewater. Samples were collected on five days, when average influent BOD_5 and total nitrogen were 500 mg/ℓ and 30 mg/ℓ, respectively.

The ordinate of Figures 23 and 24 is concentration (C) divided by initial concentration (C_o), of BOD_5 and total nitrogen, respectively. The abscissa is distance of overland flow, a non-linear function of reaction time. The velocity of wastewater flow decreased with distance down the overland flow plot, due to loss of water to percolation and evapotranspiration. In general, reaction or detention time on the top section of the plots were lower than reaction time on a downhill section of equal size.

The rate of carbon oxidation was high at the top of the plot, and slowed down considerably over the bottom three-quarters of field length. Removal of nitrogen per flow distance was more constant for three-quarters of the plot length.

A brief summary of data given in Appendix Table A-4 is presented in Table 18. The following mechanisms of carbon and nitrogen removal are proposed through interpretation of that data.

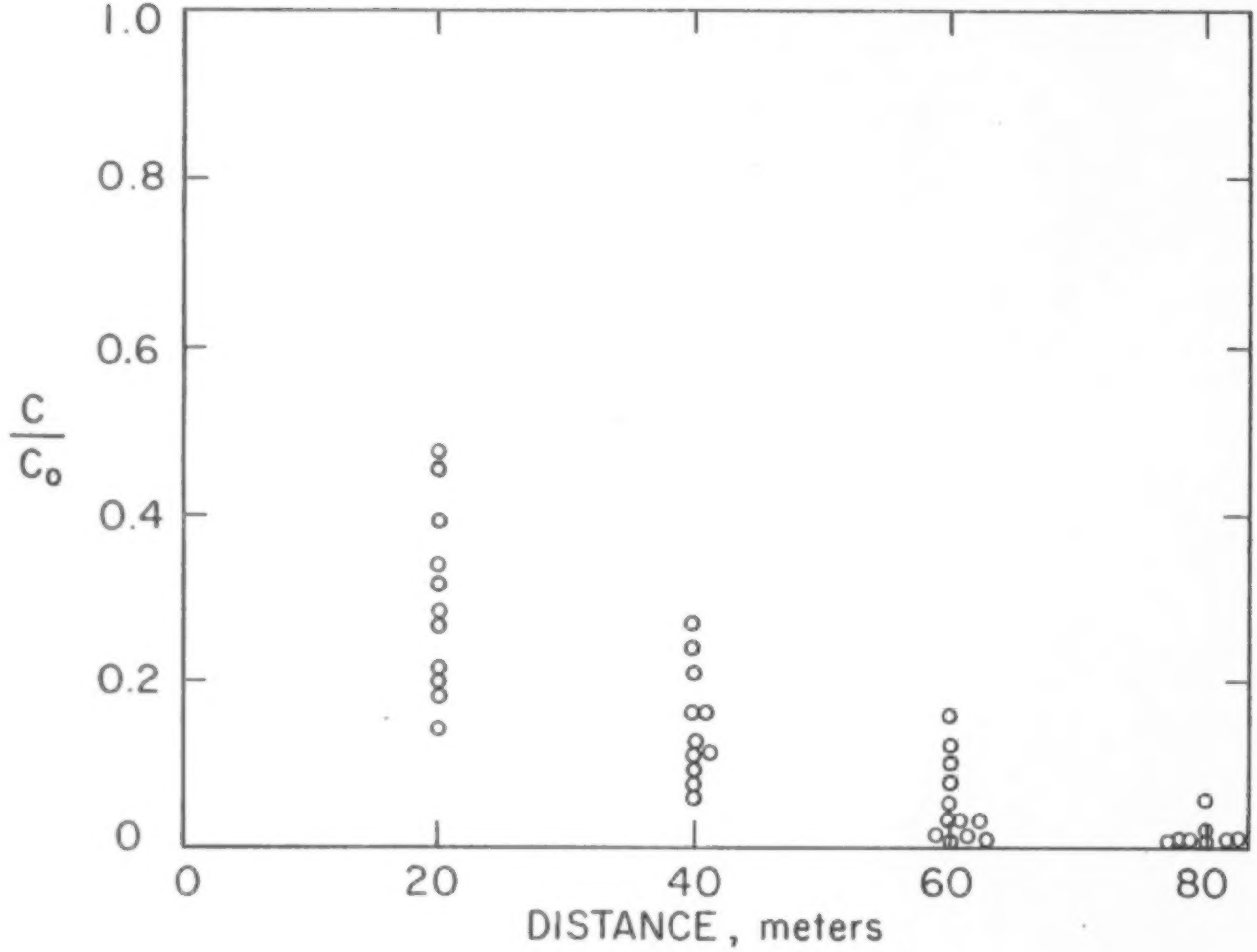


Figure 23. Fraction of BOD_5 remaining with distance of overland flow.

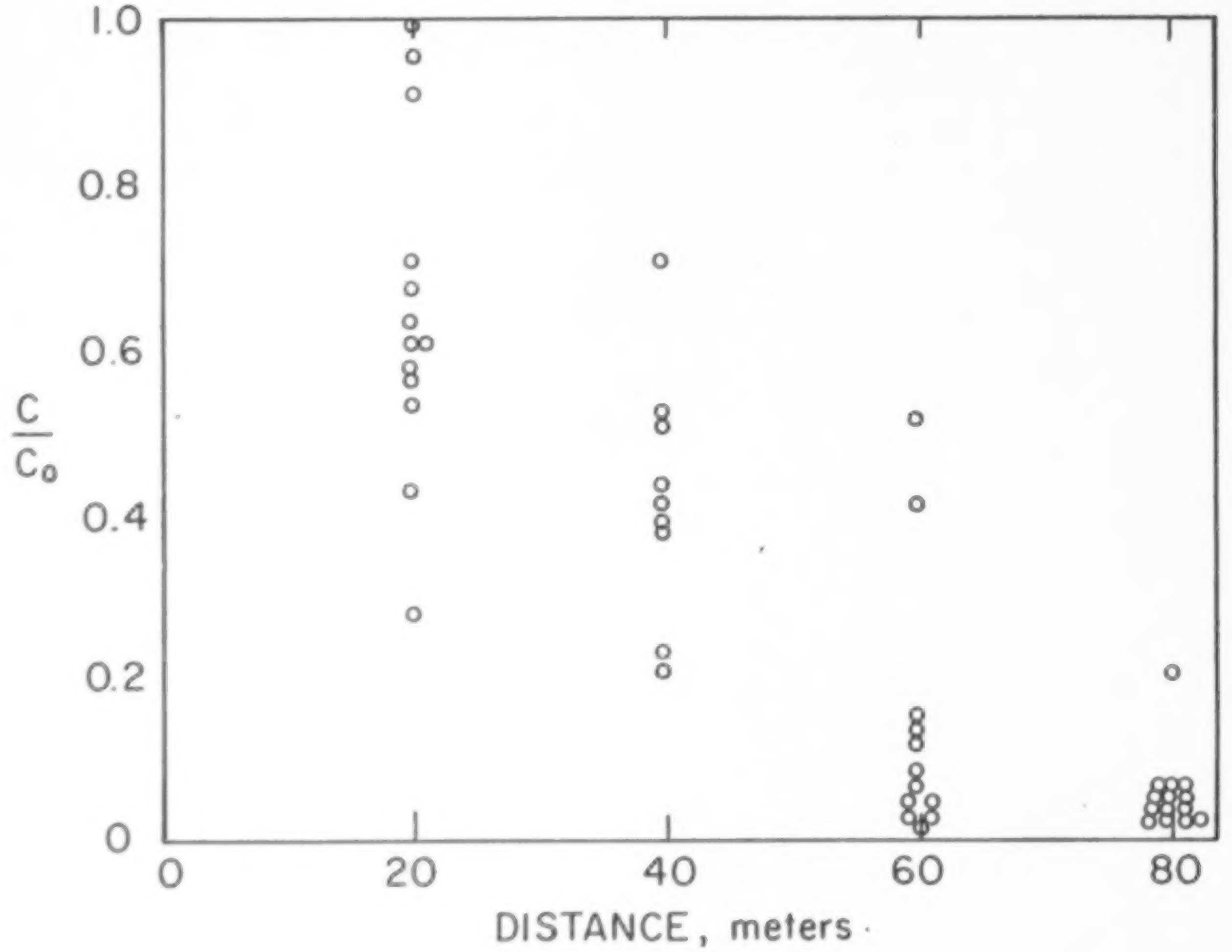


Figure 24. Fraction of total nitrogen remaining with distance of overland flow.

TABLE 18. RELATIONSHIPS OF NITROGEN AND BOD_5 ALONG THE OVERLAND FLOW PLOT*

Distance from application point	BOD_5 (mg/ℓ)	Total Nitrogen (N_T) (mg/ℓ)	BOD_5 to N_T removal ratio	BOD_5 to N_T concentration ratio
0 meters (raw wastewater)	500	30		17:1
Top Quarter			33:1	
20 meters	155	20		8:1
Second Quarter			11:1	
40 meters	80	13		6:1
Third Quarter			5:1	
60 meters	35	4		9:1
Bottom Quarter			14:1	
80 meters (effluent)	8	2		4:1

* Samples collected during Fall monitoring period, for both the North and South plots.

On the top one-quarter of the plot, 33 mg of BOD_5 was removed for every 1 mg of nitrogen removed. That indicated that the microbial population was dominated by heterotrophs rapidly oxidizing the carbon to carbon dioxide. The large amounts of oxygen consumed (650 kg/ha/day) indicated that all available oxygen was consumed by heterotrophs, and anoxic conditions prevailed. Plant uptake, and incorporation in the increasing biomass were the probable nitrogen removal mechanisms. The soil water pH of about 7.5 indicated that ammonia volatilization was also taking place.

On the second one-quarter of the plots, the ratio of BOD_5 removed to nitrogen removed was 11:1. Average BOD_5 concentration decreased from 155 to 80 mg/ℓ on that section. Oxygen consumption probably still limited nitrification, and ammonia volatilization was less significant due to decreased ammonia concentration.

Nitrate nitrogen found in samples collected at the end of the third one-quarter indicated that nitrification was taking place. For the biofilm reactor tested by Williamson and McCarty (15), oxygen transport ceased to limit nitrification when BOD_5 dropped to a concentration of about 40 mg/ℓ. For that overland flow biofilm system, oxygen transport was sufficient for nitrification when BOD_5 was between 80 mg/ℓ and 35 mg/ℓ.

In a review of the literature it was found that conditions should favor denitrification throughout an overland flow plot, provided the carbon to nitrate ratio was equal to or greater than 2:1. On the third one-quarter of the plot, where nitrification was taking place, BOD_5 to total nitrogen ratios varied from 6:1 to 9:1. Therefore, carbon should not have limited denitrification. The ratio of BOD_5 removal to nitrogen removed decreased to 5:1 over this section. That low ratio supported the suggestion that an effective nitrogen removal mechanism such as denitrification must have been taking place.

Over the final one-quarter of the plot, BOD_5 was 35 mg/ℓ or less, and oxygen consumption was less than 30 kg/ha/day. Most nitrogen in the effluent was in an oxidized form. The oxidized nitrogen probably passed through reduced zones before reaching the effluent, yet it was not subjected to dissimilatory reduction. The BOD_5 to nitrate ratio of the effluent was about 4:1, thus a low carbon to nitrogen ratio should not have limited the reaction. Possibly the rate of reaction was retarded by low concentrations of carbon and nitrate. It is also possible that the carbon was an insoluble form, and not available to denitrifying bacteria.

The nitrogen loading to the bottom one-quarter of the plot was about 5 kg/ha/day. During peak growing seasons, the grass crop would utilize all of that nitrogen. On an average day during the growing season, the crop would be capable of using about 40% of the nitrogen. Plant uptake could account for about 10% of the nitrogen removal on the three uphill sections.

Decreased detention time would have the same effect as decreasing plot length. The high initial BOD_5 removal rate would make BOD_5 less sensitive to decreased detention time than nitrogen. That is discussed later in more detail.

This study was performed during warm weather operation (average temperature of 24°C). The effect of winter conditions on oxygen transport, microbial carbon and nitrogen transformations, and plant growth would change the shape of "C/C_0 vs. distance" profiles. That would preclude applicability of the curves to cold weather operation.

Effect of Continuous Application on Effluent Quality

During each water application cycle, the soil environment underwent a series of changes which were often reflected in the effluent characteristics. At the beginning of each cycle, oxidized conditions prevailed and processes such as nitrification and oxidation of carbon took place. Reduced conditions gradually spread throughout the plot, starting near the point of application. There was a time in which there was a relatively oxidized zone at the soil surface, and reduced conditions below. Eventually reduced conditions prevailed throughout the plot. At that time wastewater application should have ceased, to allow drying and reaeration of the soil.

During the drying of the soil, adsorbed ammonium ions were oxidized to nitrate by soil microorganisms, renewing adsorption sites. Many land treatment systems are operated with the intent of treating nitrogen by adsorption during application, followed by nitrification while the soil dries. Wastewater is applied until a breakthrough of ammonia takes place, indicating that the saturation of ammonium ion adsorption sites. That type of operation was attempted at the site during the summer monitoring period.

A clear breakthrough, as indicated by a sharp increase in effluent ammonia, did not occur during summer operation. However, effluent ammonia concentrations gradually increased during five of the seven application periods which followed several days or more of drying. One of the two exceptions occurred during the first cycle, which followed a very long period without wastewater application. On the first few days of that cycle, system performance was poor. The decrease in effluent ammonia after three days of application may indicate an increased microbial population. The resultant improvement in effluent quality would compete with the breakthrough effect.

Effluent nitrate changed independently of the time of continuous application, being stable at a concentration from 1 to 3 mg/ℓ at the end of each cycle. On one occasion, after 120 hours of wastewater application a significant rise in effluent ammonia accompanied a drop in nitrate to less than 1 mg/ℓ. That indicated reduced conditions, and the plot was allowed to dry.

Effluent BOD_5 was not affected by continuous application in the same manner as effluent ammonia. There were two factors which may have contributed to that difference. BOD_5 removal was not as greatly affected by reduced conditions as nitrogen removal, as detention time was sufficiently long to allow carbon oxidation with a limited supply of oxygen. Secondly, oxygen demand was not greatly affected by an adsorption process, thus a saturation of sites during application of wastewater would not affect effluent BOD_5.

Figure 25 shows an apparent proportionality of effluent nitrogen, but not BOD_5, to hours of continuous application. Suspended solids was not plotted but also appeared to be independent of the number of consecutive hours of wastewater application.

Effluent Flow and Effluent Quality

Shortcircuiting of wastewater and increased hydraulic loading both resulted in an increase in effluent flow. Shortcircuiting caused a decrease in detention time and soil contact, leading to poorer effluent quality. Increased hydraulic loading could have also decreased detention time, assuming the volume of water on the plot was constant.

The fraction of total effluent which traveled above the bentonite seal and downhill through the soil, as opposed to that which passed over the soil, could have also influenced effluent quality. The portion passing through the soil generally had less nitrogen, suspended solids and BOD_5 than the surface runoff.

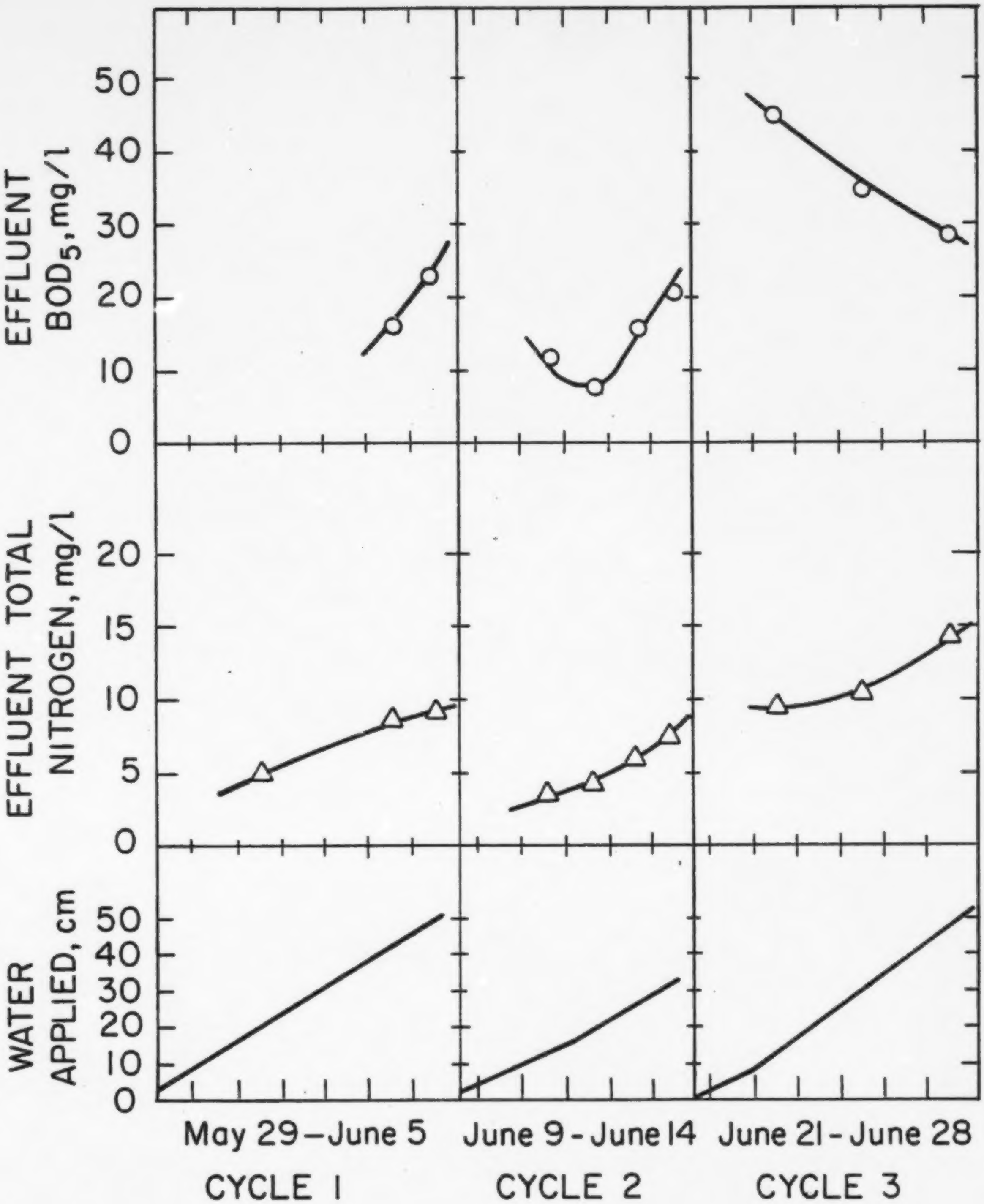


Figure 25. The effect of continuous application on effluent quality (Summer data from the South Plot).

That portion increased when effluent flow decreased because movement through the soil remained relatively constant when the soil was saturated. That was another factor leading to improved effluent with decreased effluent flow.

The portion moving downhill through the topsoil layer could not be measured directly, but use of Darcy's Law led to an estimation of 2.2 m^3/d. Therefore, that flow varied from 3% to 20% of effluent flow, and was less than 10% of the average effluent flow. That small fraction could have made the effect of water movement through the topsoil on overall effluent quality small.

During the fall and summer periods, the response of effluent nitrogen to effluent flow was clear. This is illustrated in Figure 26. A linear regression of nitrogen against effluent flow for the 12 June samples yielded a correlation coefficient, r, of 0.92. September data was insufficient to perform a meaningful statistical analysis.

That relationship was less apparent for soluble and total BOD_5 and COD during the summer and fall periods, as is shown in Figure 27.

It was not surprising that nitrogen should be affected more than oxygen demand by a decrease in detention time. Nitrogen removal by nitrification-denitrification was initially slower than carbon oxidation. Most of the soluble oxygen demand had been removed after travelling less than one-half of the length of the plot. The rate of carbon oxidation then decreased such that small changes in reaction time did not control changes in effluent oxygen demand.

During summer operation, effluent flow usually increased with increasing time of continuous water application. Effluent nitrogen concentration was inversely related to both, and the effect of each separately could not be determined. The combination of those two factors apparently influenced nitrogen treatment when temperature was not limiting.

During the winter and spring monitoring periods, the effect of varying detention time was not noticeable. Other factors, including temperature fluctuation and changes in microbial population exerted a greater effect on carbon and nitrogen transformations during February, March and April.

The relationship between effluent quality and effluent flow was not direct. Effluent flow was used to indicate that other factors, which affect effluent quality more directly, were varying. The concentration to flow ratio was not the same in September as in June for nitrogen or oxygen demand, showing that while the trend did exist, it was not possible to predict effluent concentrations from effluent flow.

Effluent flow rates increased when rainfall occurred during overland flow treatment. Data collected during periods of short intense rainfalls are shown in Appendix Table A-6. No substantial change in effluent quality was observed during those rainfall periods.

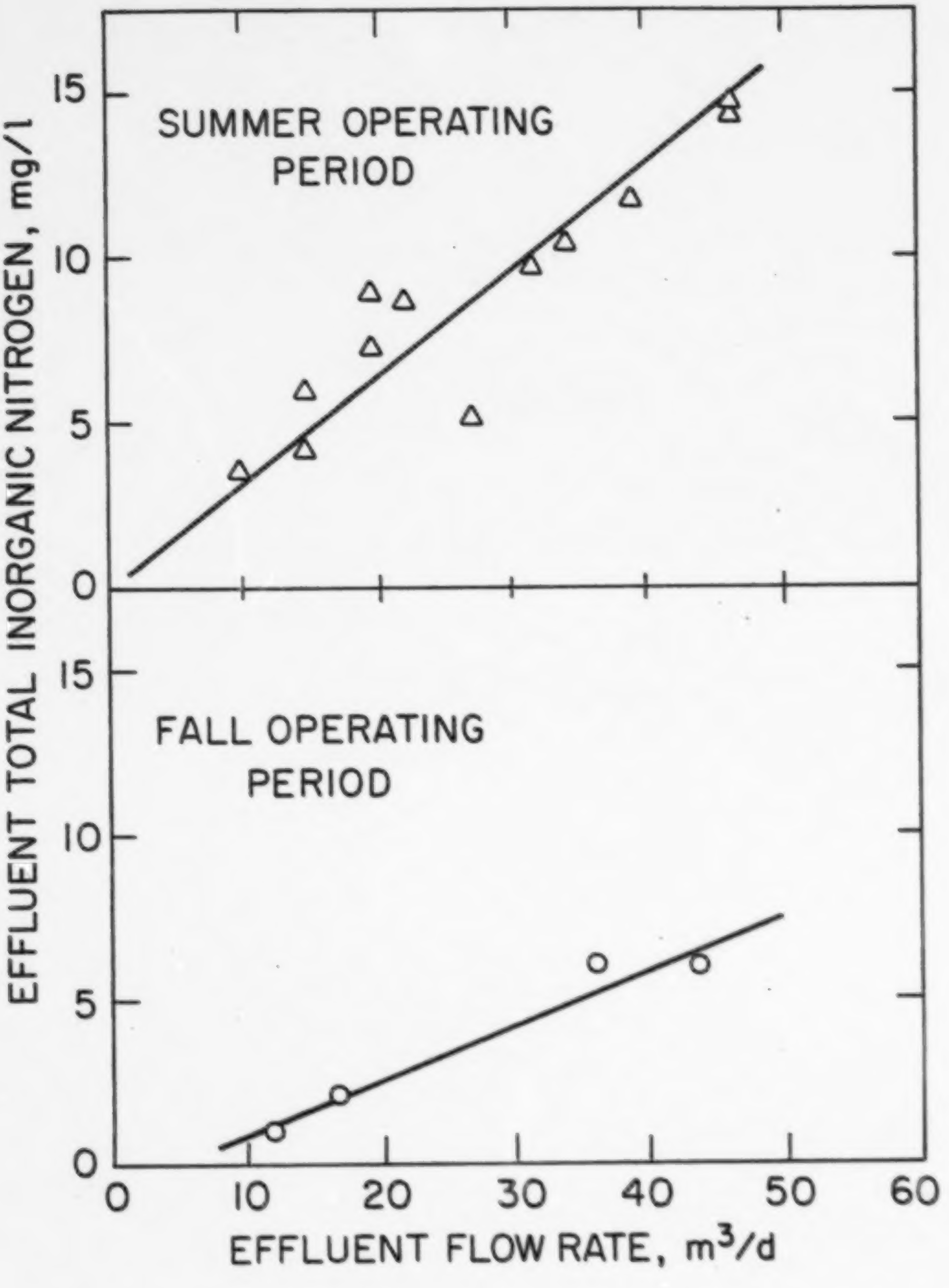


Figure 26. Effluent total nitrogen vs. effluent flow rate during warm weather operation.

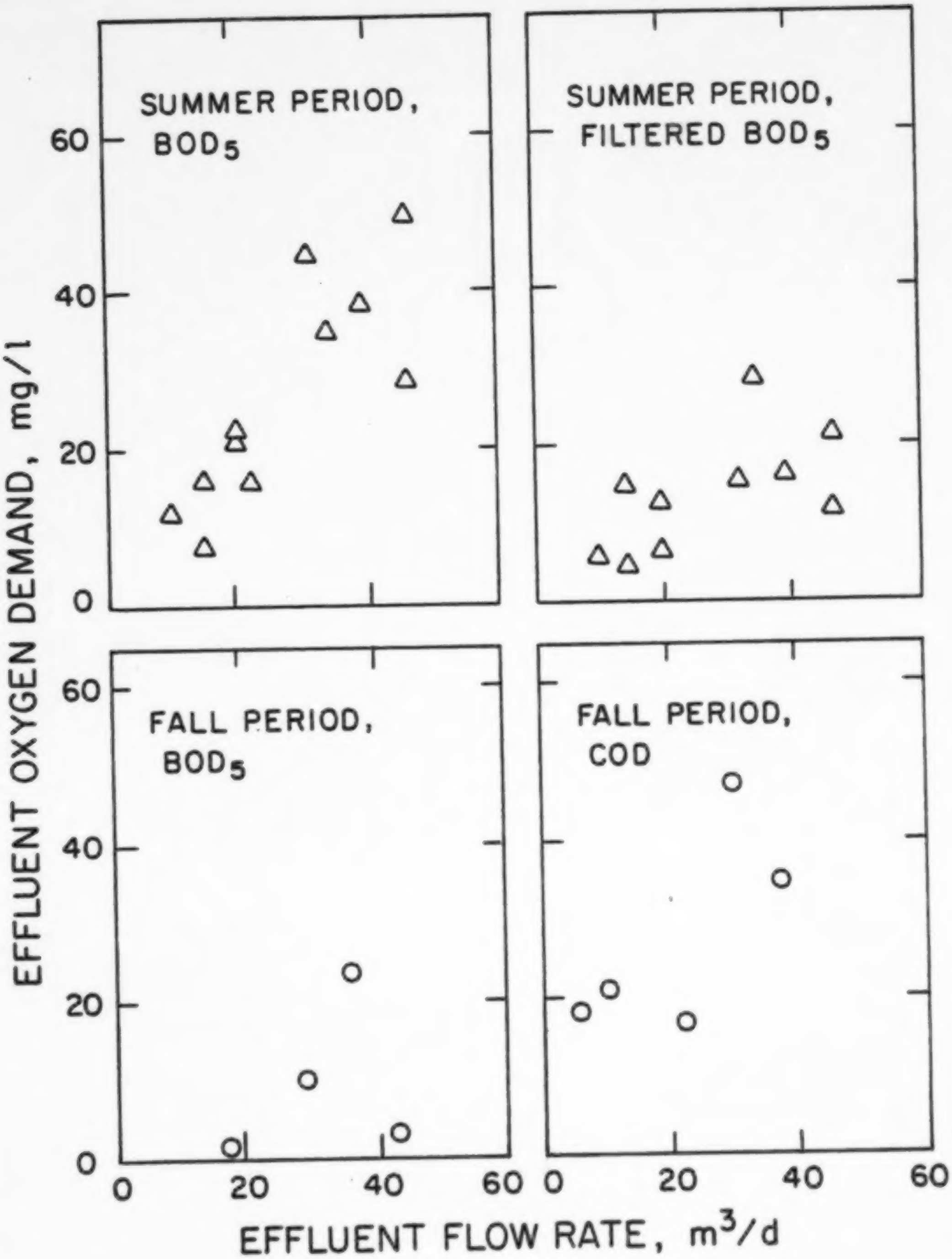


Figure 27. Effluent oxygen demand vs. effluent flow rate during warm weather operation.

Effects of Algae

The presence of algae on the overland flow plot and in the effluent reduced the overall system performance. Algae was a problem particularly in the last two weeks of the summer operation period.

At that time, effluent BOD_5 was nearly double that of previous periods, reaching an average of 40 mg/ℓ for the South Plot, and 35 mg/ℓ from the North Plot. Suspended solids and organic nitrogen increased to more than double the effluent concentrations of the previous operation period.

Algae caused problems at the overland flow sites in two ways. First, the presence of algae in the effluent caused a rise in nitrogen, carbon and suspended solids. That excess could be eliminated by removing the algae by chemical treatment or filtration. Second, the presence of algae on the overland flow plot itself led to the buildup of algal mats. Those mats hold moisture in the soil, and sealed the soil from the air above. That hindered drying and aeration of the soil which was important for aerobic nitrogen and carbon transformation. In that way, algae caused effluent ammonia and soluble BOD_5 concentrations to increase.

The effect of the algae in the influent was studied by comparing soluble BOD_5 with total BOD_5, and by comparing organic nitrogen and suspended solids with those two parameters during the previous operating periods.

The difference between filtered and total BOD_5 was 22 mg/ℓ and 15 mg/ℓ for the South and North plots, respectively. Some of that difference may have been due to factors other than algae in the effluent, but algae was certainly the dominating influence. Once the algae were filtered out, effluent BOD_5 was similar to that in previous operating periods, about 20 mg/ℓ. (See Table 19).

TABLE 19. EFFECTS OF ALGAE

Period	Plot	Average effluent concentrations, mg/ℓ				
		Organic nitrogen	Soluble nitrogen	BOD_5	Soluble* BOD_5	Suspended solids
Fall	North	1	3	7	n.a.	n.a.
Spring	North	1	9	22	n.a.	10
Early summer	South	1	6	16	10	12
Algae Problems:						
Mid-summer	South	4	12	40	18	60
	North	6	7	35	20	35

* Soluble BOD_5 was measured as filtered BOD_5.

Organic nitrogen in the effluent averaged 5 mg/ℓ during the severe algae problem periods. During all other periods of operation, organic nitrogen averaged 1 mg/ℓ. That increase of 4 mg/ℓ of organic nitrogen was probably directly attributable to the presence of algal cells.

Suspended solids concentration in the effluent averaged 60 mg/ℓ and 35 mg/ℓ for the South and North Plots, respectively. During previous periods of operation, suspended solids averaged about 20 mg/ℓ or less.

A few individual samples showed a relationship between an increase in suspended solids and an increase in insoluble BOD_5 or organic nitrogen. On the average, an increase of about 30 mg/ℓ of suspended solids, due to algae, brought about an increase of about 12 to 15 mg/ℓ of BOD_5 and 4 mg/ℓ of organic nitrogen.

Organic nitrogen, insoluble oxygen demand and suspended solids were all measures of the effect of algae in the effluent. Investigation of the effect of algal mats on the soil surface was more subtle and could not be done conclusively with the data presented here. Soluble nitrogen and oxygen demand in the effluent from previous periods was compared with that during algae problems. Effluent quality was not as good as that during the fall period, although that may also be attributed to other factors such as increased loading. Soluble nitrogen and BOD_5 were no better than the previous spring, when the air temperature was 15°C lower.

It is not clear how to prevent algal problems such as those which developed at the overland flow site. The problems rose directly from the use of the storage lagoon prior to overland flow treatment. While previous mechanical problems were overcome when raw wastewater was no longer used, the algae in the storage lagoon presented a new problem. Other overland flow operators have relied on a dense grass cover to prevent sunlight penetration and subsequent development of algae (1). Those sites, however, did not apply algae with the wastewater.

Summary

During periods of warm weather, temperature variation appeared to have little effect on COD, BOD_5 and nitrogen removal. Other factors such as loading rate and detention time appeared to have a greater effect on nitrogen removal. That was due mainly to the high initial rate of BOD_5 removal. About two-thirds of the applied BOD_5 was removed in the top one-quarter of the overland flow plot.

Data interpretation with respect to loading rate was difficult due to frequent rate variation. It appeared that an effluent quality of 20 mg/ℓ of BOD_5, 20 mg/ℓ of suspended solids and 4 mg/ℓ of ammonia nitrogen, or better, could be maintained at a hydraulic loading of from 20 to 30 cm/wk during warm weather.

Continuous application of wastewater for several days, followed by two or three days of drying may be an effective overland flow application cycle. Monitoring of effluent ammonia could be a useful method for determining the length of application time. The length of drying time would depend mainly on evapotranspiration and precipitation.

Algae applied with lagoon wastewater caused growth of algal mats on the plot. That resulted in increased effluent suspended solids, BOD_5 and total nitrogen. The best solution to algae problems could be to minimize or eliminate the application of wastewater from a storage lagoon. (That would necessitate a well designed and operated pretreatment system for solids removal, in order to protect the wastewater application pumps, and off-line winter storage that could be completely drained before algae developed). A dense grass cover and application of virtually no algae would prevent establishment of algal mats and the concommitant problems.

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APPENDIX A

TABLE A-1. INFLUENT CHARACTERISTICS

Sample collection date and source[a]	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100 mL
3/21/78,B			170		250		6	<0.2	33	2.7		
3/22/78,L			95		230		3	<0.2	23	0.6		
8/7/78,L	7.9	27	36	65	60		6.5	0.2	8.7	2.4		
9/5/78,B	7.0				215		8.6	<0.2	16.0			
9/7/78,B	7.0		170		530			<0.2	62	3.9		
9/12/78,B	7.3		350		350				25	2.5		
9/15/78,B,	7.2		500		645		10.3	<0.2		2.7		
9/19/78,B	7.1		660		765		16.8	<0.2	37	1.2		
9/27/78,L			150		175		7.3	1.5	17.6	2.5		
2/1/79,L			195									
2/8/79,L	8.0	140	205	210	360	115	60	<0.2	53	2.8	16	
2/20/79,B			420		690	180	5	<0.2	25	2.0	23	
2/20/79,W			360		350	105	5	<0.2	21	3.9	63	
3/21/79,B			230		695	200	6.7	<0.2	30	2.5		
3/21/79,W			155		255	80	2.0		33	6.8		
3/22/79,B			370		585	195	5.3		38			
3/22/79,W			115		145	35	1.7		10	6.2		
3/25/79,L			165		180	90	16.7			2.9		
4/1/79,L					170	70	13.5	<0.2	20	2.0		
4/3/79,L					145	95	11.0	<0.2				
4/4/79,B			270		360	280	9.6	<0.2	38	2.7		
4/4/79,W			215		310	190	2.9	<0.2	20	4.0		
4/7/79,L			76			90	17.1			7.4		

(continued)

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[a] [illegible] three wastewater sources: L = latrine water; W = wash photo processing water; B = [illegible] photo processing water.

TABLE A-1. (Continued)

Sample collection date and source*	pH	BOD, mg/L		COD, mg/L		SS mg/L	Nitrogen, mg/L as N			Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100 mL
		filtered	unfiltered	filtered	unfiltered		NH_3	NO_2+NO_3	TKN			
4/19/79,K			510			190	6.6	<0.2	50			
6/1/79,L							19.0					
6/4/79,L			124				17.1			3.1		
6/5/79,L		70	130			128	16.1	0.04	28			125,000
6/12/79,L	7.0					146	14.2	0.05	31.2	2.8		
6/13/79,L		203	345									
6/20/79,L	7.2	38	149			200	14.9	0.08	35.8	3.3	8	
7/3/79,L	7.5	47	99			182	17.0	0.10	36.7	3.3		

TABLE A-2. NORTH PLOT EFFLUENT CHARACTERISTICS

Sample collection date	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100 mL
8/7/78		No Effluent										
9/5/78	8.1						0.3	<0.2	0.9			
9/7/78	8.1		2.1		21			<0.2	2.0	1.2		
9/12/78	7.8		24		48				5.3	4.0		
9/15/78	7.7		3.0		35		1.2	4	1.7	2.1		
9/19/78	7.7		10.2		17		1.0	3	1.4	1.8		
9/27/78		No Effluent										
2/3/79	8.8		250				145	<0.2				
2/9/79		No Effluent										
2/13/79			195		360	50	52	<0.2	55			
2/14/79	7.9		240		455	55	53	<0.2	55	5.6		
2/15/79			155		285	30	37					
2/16/79			140		260	25	33					
2/20/79			90		110	30	58			2.8		
2/22/79			95		150		21			2.9	7	
2/23/79			50		80		13	<0.2	15			
2/28/79			95		195		27			2.8		
3/3/79			25		55	35	6.6			1.6		
3/4/79			<20		48		6.3		8.2	1.9		
3/6/79			45		98	10	18.0			3.4		

(continued)

TABLE A-2. (Continued)

Sample collection date	pH	BOD, mg/L		COD, mg/L		SS mg/L	Nitrogen, mg/L as N			Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100mL
		filtered	unfiltered	filtered	unfiltered		NH_3	NO_2+NO_3	TKN			
3/9/79			20		53	20	13.5	<0.2		2.8		
3/10/79			21		75	15	19.0	<0.2		3.5		
3/14/79			20		78	35	14.0	<0.2		2.4		
3/20/79			22		63	30	15.0	<0.2		2.9		
3/21/79			10		44	10	12.5	<0.2	15	2.9		
3/22/79			10		41	5	12.0	<0.2	13			
3/25/79			34		71	20	10.2	<0.2		1.9		
3/27/79			26		61	10	13.1	<0.2		2.4		
4/1/79					62	20	12.5		11	1.7		
4/3/79			19		65	10	9.7	0.6				
4/4/79			21		62	5	6.4	0.3	6.1	4.7		
4/5/79			14		41	10	4.9	0.3		2.6		
4/7/79			52			10	16.0	<0.2				
4/19/79			18			10	3.9	0.5	4.5	1.0		
4/26/79			23			20	3.4	0.7				
6/7/79	8.5	19	29			22	13.5	1.2				2,016
6/8/79	8.2	29	28			13	11.0	2.4	17.9	2.9	<5	
6/20/79	7.7	12	45			83	3.8	1.0	13.7	2.2	8	
6/21/79	7.8	20	35			42	5.3	2.2				
7/2/79		20	36			31	6.1	1.6				
7/3/79	7.0	15	23			32	4.8	1.4	5.8	2.4		

TABLE A-3. SOUTH PLOT EFFLUENT CHARACTERISTICS

Sample collection date	pH	BOD, mg/L		COD, mg/L		SS mg/L	Nitrogen, mg/L as N			Total P mg/L as P	Oil & grease mg/L	Total coliform no., per 100 mL
		filtered	unfiltered	filtered	unfiltered		NH_3	$NO_2 + NO_3$	TKN			
3/21/78			7		80		4	<0.2	10	0.7		
3/22/78			24		45		3	<0.2	3	1.2		
8/7/78		No Effluent										
9/5/78		No Effluent										
9/7/78	8.1		5.7		10			<0.2	1.3			
9/12/78	7.8		4.4		29				1.4	2.5		
9/15/78	7.7		3.2		20		1.0	4	1.2	1.8		
9/19/78	7.8		5.0		12		0.4	4	1.1	2.1		
9/27/78		No Effluent										
2/22/79			65		115		19	<0.2		3.0		
2/23/79			50		70	10	7.5		8.8		8	
2/28/79			70		140	35	27			2.8		
3/3/79			50		70	20	5.3			1.0		
3/4/79			<30		56		6.1	<0.2	7.0	1.0		
6/1/79							5.0					
6/4/79			16				8.4	0.2		2.1		
6/5/79	8.4	13	23			9	8.1	0.8	13.0			1,000
6/11/79	7.8	6	12			14	3.3					
6/12/79	7.8	5	8			10	1.8	2.3	5.0	1.8		1,010
6/13/79	7.4	15	16			11	3.1	2.9				
6/14/79		7	21			18	4.2	3.0				
6/23/79	7.7	16	45			62	5.3	4.3				
6/25/79	7.4	29	35			57	8.4	2.0				
6/27/79	7.6	12	29			77	13.6	0.8	17.1	1.9		6,160
7/2/79		17	39			42	9.0	2.7				
7/3/79	7.7	21	50				11.9	2.7	12.6	2.9		

TABLE A-4. ON-PLOT SAMPLE CHARACTERISTICS

Location and date *	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100 mL
9/5/78												
INFL.	7.0				215		6.4	<0.2	16.0			
A-1					145		7.8		6.9			
A-3					60		9.2		11.4			
A-6					65		7.8		10.9			
B-1							10.8		16			
B-6							7.8		11.3			
C-1							7.9		8.2			
C-5							0.7		1.9			
EFFL.S		No Effluent										
EFFL.N	8.1						0.3	<0.2	0.9			
9/7/78												
INFL.	7.0		320		530			<0.2	42	3.9		
A-1	7.2		105		200				11.7	1.8		
A-2	7.3		45		85				4.5	1.6		
A-3	7.2		125		255				23	3.0		
A-4	7.3		85		145					1.6		
A-5	7.2		145		190				26	2.7		
A-6	7.2		145		240				26	2.6		
B-1	7.3		85		120				17.5	2.5		
B-2	7.9		> 90		135				16.5	2.7		
B-3	7.7		40		65				9.7	1.8		
B-4	7.2		40		85				8.8	2.1		
B-5	7.7		25		25					1.5		
B-6	7.6		50		50					2.0		
C-1	7.2		8.5		40				1.8	1.7		
C-3	7.8		10.0		65				1.3	1.1		
C-4	7.6		6.5		55				1.6	1.1		
C-5	7.3		10.5		55				1.0	1.3		

(continued)

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* Locations A,B and C are respectively 20, 40 and 60 m from the top of the plot. The numbers 1 through 6 give the location across the plots as follows: North Plot: 2 is at the center and 1 and 3 at one-quarter points, South Plot: 5 is at the center and 4 and 6 at one-quarter points.

TABLE A-4. (continued)

Location and date	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100mL
9/7/78 (continued)												
C-6	7.5		25		55				3.0	1.2		
EFFL.S	8.1		5.7		10			<0.2	1.3			
EFFL.N	8.1		2.1		21			<0.2	2.0	1.2		
9/12/78												
INFL.	7.3		350		350				25	2.5		
A-1			110		200				23	2.3		
A-4			100		205				25	2.5		
A-6					180					2.6		
B-1			90		170					2.6		
B-4			55		80				14	2.2		
C-1			45		65					2.3		
C-4			23		45				2.1	1.7		
EFFL.S	7.8		4.4		29				1.4	2.5		
EFFL.N	7.8		24		48				5.3	4.0		
9/15/78												
INFL	7.2		500		615		18.3	<0.2		2.7		
A-4			80		105		12.5	<0.2	15	2.2		
B-4			30		40		7.6	<0.2		1.7		
C-4			<10		35		2.1	4	1.0	3.9		
EFFL.S	7.7		3.2		20		1.0	4	1.2	1.8		
EFFL.N	7.7		3.0		35		1.2	4	1.7	2.1		

(continued)

TABLE A-4. (Continued)

Location and date	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per100 mL
9/19/78												
INFL	7.1		660		745		16.8	<0.2	37	1.2		
A-1	7.4		145		195		24	<0.2	21	1.4		
A-4	7.3		125		165		19.0	<0.2	20	1.5		
B-1	7.1		140		145		16.5	<0.2	16.2	2.5		
B-4	7.3		80		80		14.0	<0.2	14.5	2.2		
C-1	7.4		>95		105		8.4	1	15.0	2.9		
C-4	7.5		21		50		3.7	2		2.0		
C-5	7.5		>60		75		7.8	4	7.7	2.4		
EFFL.S	7.8		5.0		12		0.4	4	1.1	2.1		
EFFL.N	7.7		10.2		17		1.0	3	1.4	1.8		

TABLE A-5. IN-PLANT WASTEWATER CHARACTERISTICS

Source and date *	pH	BOD, mg/L filtered	BOD, mg/L unfiltered	COD, mg/L filtered	COD, mg/L unfiltered	SS mg/L	Nitrogen, mg/L as N NH_3	Nitrogen, mg/L as N NO_2+NO_3	Nitrogen, mg/L as N TKN	Total P mg/L as P	Oil & grease mg/L	Total coliform no. per 100 mL
2/20/79												
Kill Period:											23	
Comp I			200		435	305	5.8	<0.2	14.0	1.2		
Comp. II			485		480	175	4.5	<0.2	25.5			
Comp. III			430		460	160	5.5	<0.2	27.5	2.4		
Wash:											63	
Comp. IV			260		255	90	2.4	<0.2	16.0	1.2		
Comp. V			365		370	135	5.5	<0.2	14.5	2.3		
Comp. VI			660		515	340	7.5	<0.2	28.0	3.9		
Comp. VII			195		220	135	2.3	<0.2	14.0	5.4		

*Sampling periods and methods of compositing are discussed in the text.

TABLE A-6. EFFLUENT CHARACTERISTICS DURING RAINFALL

Sample collection date	pH	BOD, mg/L		SS	Nitrogen, mg/L as N				Oil and grease
		filtered	unfiltered	mg/L	NH_3	NO_2+NO_3	TKN	mg/L as P	mg/L
South Plot									
6/20/79 †	7.4		13	38	1.0	0.5	2.5	1.5	
North Plot									
6/7/79 *	7.9			21	13.2	1.1			
6/20/79 †	7.7	16	69	98	4.0	0.9	14.3	2.0	10
6/20/79 #	7.6	14	55	79	6.0	1.8			
6/20/79 x	7.7	17	30	81	4.7	1.9			

* Grab sample taken during peak effluent from short intense rainfall.

† Composite of 6 grab samples taken during effluent peak, one sample every 10 minutes of 60 minutes.

# Grab sample taken just before rain period.

x Composite sample taken for 3 hours after effluent returned to normal following the rain.

APPENDIX B

TABLE B-1. OVERLAND FLOW OPERATING HISTORY

Date	Event	Comments	No. of pumps	No. of days
Feb. 22, 1978	Water on South Plot	North Plot pumps not yet installed	1	83
May 15, 1978	Water off Both Plots	to complete construction	0	30
June 15, 1978	Water on Both Plots	16 hr/d, 7 d/wk, 15 cm/wk	2	28
July 12, 1978	Water off Both Plots	to correct shortcircuiting and cut grass	0	27
Aug. 7, 1978	Water on Both Plots	16 hr/d, 7 d/wk, 15 cm/wk	2	7
Aug. 14, 1978	Cycle Changed Both Plots	24 hr/d, 7 d/wk, 25 cm/wk	2	42
Sept. 24, 1978	Water off Both Plots	to allow aeration of soil, cut grass and install timers	0	35
Oct. 28, 1978	Water on North Plot	15 hr/d, 7 d/wk, 18 cm/wk		
	Water off South Plot	pump failure	1	29
Nov. 25, 1978	Water off North Plot	pump failure	0	19
Dec. 13, 1978	Water on North Plot	8 hr/d, 7 d/wk, 9 cm/wk	1	11

(continued)

TABLE B-1. (continued)

Date	Event	Comments	No. of pumps	No. of days
Dec. 23, 1978	Water off North Plot	pump failure	0	37
Jan. 28, 1979	Water on North Plot	variable cycle		
Feb. 1, 1979	Ammonia spill	process plant	1	36
Mar. 4, 1979	Water off North Plot	snow-melt	0	2
Mar. 6, 1979	Water on North Plot	10 hr/d, 7 d/wk, 16 cm/wk	1	52
Apr. 26, 1979	Water off North Plot	to harvest and replant grass	0	14
May 9, 1979	Water on Both Plots	24 hr/d, 5 d/wk	2	4
May 12, 1979	Water off North Plot	pump failure	1	1
May 13, 1979	Water off South Plot	to move pump from manhole to lagoon	0	17
May 29, 1979	Water on Both Plots	N & S alternating, variable schedule	1	33
June 30, 1979	Water on Both Plots	second pump installed	2	7
July 6, 1979	Water off Both Plots		0	

TABLE B-2. FALL PERIOD WATER BALANCE, NORTH PLOT*

Date	Wastewater (m^3)	Rain (m^3)	Total influent (m^3)	Effluent (m^3)	Pan evaporation (m^3)	Percolation (m^3)
9/5/78	60		60	10	5	45
9/6	60		60	10	10	40
9/7	60		60	15	10	35
9/8	60		60	25	10	25
9/9	60		60	25	15	20
9/10	60		60	25	10	25
9/11	60		60	25	10	25
9/12	60		60	35	5	20
9/13	60	35	95	45	10	40
9/14	60	20	80	40	0	40
9/15	60		60	30	5	25
9/16	60		60	35	5	20
9/17	60	25	85	30	5	50
9/18	60	5	65	30	5	30
9/19	60	8	60	30	5	25
TOTAL	900	85	985	410	110	465

* Influent flow measurement during this period was infrequent, and probably not representative. The effluent flow recorder was calibrated infrequently, causing questionable accuracy. Water mass balances from this period were calcuated only for the North plot from 9/5-9/19. Average estimated percolation rate was 2.2 cm/d.

TABLE B-3. WINTER PERIOD APPLICATION SCHEDULE

Date	Pumping to North Plot	Process plant operation
Jan. 28, 1979 (Sun).	12M to 12M	none
29	12M to 12M	6AM to 5PM
30	12M to 12M	6AM to 4PM
31	12M to 8AM	6AM to 5PM
Feb. 1, 1979	none	6AM to 3PM
2	3PM to 12M	none
3	12M to 4PM	none
4 (Sun).	6AM to 4PM	none
5	6AM to 4PM	none
6	6AM to 4PM	6AM to 4PM
7	6AM to 4PM	6AM to 5PM
8	none	none
9	none	none
10	none	none
11 (Sun).	none	none
12	4PM to 12M	none
13	12M to 10AM & 4PM to 6PM	6AM to 5PM
14	10AM to 6PM	6AM to 4PM
15	9AM to 5PM	6AM to 3PM
16	none	none
17	9AM to 6PM	none
18 (Sun).	9AM to 12M	none
19	12M to 12M	none
20	12M to 5PM	6AM to 3PM
21	none	none
22	7AM to 5PM	6AM to 3PM
23	none	6AM to 3PM
24	11AM to 6PM	none
25 (Sun).	11AM to 5PM	none
26	7AM to 5PM	none
27	7AM to 5PM	6AM to 3PM
28	7AM to 5PM	6AM to 4PM
Mar. 1,1979	7AM to 5PM	6AM to 4PM
2	7AM to 5PM	6AM to 4PM
3	7AM to 5PM	none
4	none	none

TABLE B-4 WINTER PERIOD WATER BALANCES, NORTH PLOT

Date	Influent			Effluent	Evaporation and percolation
	Waste-water (m^3)	Precipitation* (m^3)	Total (m^3)	(m^3)	(m^3)
2/12/79	26	14	40	0	40
2/13	40		40	38	2
2/14	28		28	23	5
2/15	27		27	15	12
2/16	0		0	3	-3
2/17	31		31	13	18
2/18	50	3	53	28	25
2/19	79		79	82	-3
2/20	56		56	68	-12
2/21	0	10	10	1	9
2/22	33		33	32	1
2/23	0	18	18	46	-28 †
2/24	23		23	10	13
2/25	20		20	5	15
2/26	33		33	18	15
2/27	33		33	21	12
2/28	33		33	14	19
3/1	33	5	38	39	-1
3/2	33		33	16	17
TOTAL	578	50	628	472	156
3/3 #	33	20	53	106	-53 †
3/4 #	0	25	25	57	-32 †

* The volume presented is the water equivalent of precipitation, in the form of snow.

† Effluent volume was high due to melting of snow.

These days not included in Winter Period totals because these were days of rainfall and snow melting.

TABLE B-5. SPRING PERIOD WATER BALANCE, NORTH PLOT

DATE	Influent Waste-water (m^3)	Influent Rain (m^3)	Influent Total (m^3)	Effluent (m^3)	Evaporation and percolation (m^3)
3/6/79	33		33	1	32
3/7	33		33	11	22
3/8	33		33	8	25
3/9	33	16	49	14	35
3/10	33		33	7	26
3/11	33		33	15	18
3/12	33		33	23	10
3/13	33		33	14	19
3/14	33		33	8	25
3/15	33		33	16	17
3/16	33		33	18	15
3/17	33		34	17	17
3/18	33		33	12	21
3/19	33		33	13	20
3/20	33		33	10	23
3/21	33		33	10	23
3/22	33		33	6	27
3/23	33	15	48	23	25
3/24	33	1	34	11	23
3/25	33	2	35	14	21
3/26	33		33	13	20
3/27	33		33	12	21
3/28	33	13	46	26	20
3/29	33	30	63	39	24
3/30	33	12	45	15	30
3/31	33		33	14	19
4/1	33	5	38	14	24
4/2	33	23	56	19	37
4/3	33		33	14	19
4/4	33	10	43	28	15
4/5	33	6	39	17	22
4/6	33		33	13	20

(continued)

TABLE B-5. (continued)

DATE	Influent			Effluent (m^3)	Evaporation and percolation (m^3)
	Wastewater (m^3)	Rain (m^3)	Total (m^3)		
4/7/79	33	1	34	15	19
4/8	33	20	53	42	12
4/9	33		33	20	13
4/10	33		33	13	20
4/11	33	34	67	27	40
4/12	33	7	40	15	25
4/13	33		33	12	21
4/14	33		33	13	20
4/15	33		33	13	20
4/16	33		33	12	21
4/17	33		33	8	25
4/18	33		33	11	22
4/19	33		33	12	21
4/20	33		33	10	23
4/21	33	1	34	14	19
4/22	33		33	12	21
4/23	33		33	10	23
4/24	33	32	65	26	39
4/25	33	10	43	19	25
4/26	17	26	43	*	*
TOTAL	1700	264	1964	779	1144

* Missing data.

TABLE B-6. SUMMER PERIOD APPLICATION SCHEDULE (1979)

Water on	Water off	Plot	Hours	Days
May 29, 3:00 p.m.	June 5, 4:00 p.m.	South	169	7.0
June 5, 4:00 p.m.	June 9, 6:30 p.m.	North	98.5	4.1
June 9, 6:30 p.m.	June 14, 1:00 p.m.	South	114.5	4.8
June 14, 1:00 p.m.	June 16, 10:00 p.m.	North	57	2.4
June 16, 10:00 p.m.	June 18, 9:00 a.m.	none*	35	1.5
June 18, 9:00 a.m.	June 21, 3:00 p.m.	North	78	3.3
June 21, 3:00 p.m.	June 28, 2:00 p.m.	South	167	7.0
June 28, 2:00 p.m.	June 30, 12:00 noon	none†	46	1.9
June 30, 12:00 noon	July 3, 3:00 p.m.	North and	75	3.1
		South	75	3.1

* Electric problems

† New pump being installed

TABLE B-7. SUMMER PERIOD WATER BALANCES, NORTH PLOT

Date	Wastewater (m^3)	Rain (m^3)	Total influent (m^3)	Effluent (m^3)	Evaporation and percolation (m^3)
6/5/79	26		26	0	26
6	79		79	7	72
7	79	5	84	30	54
8	79		79	29	50
9	61		61	28	33
10	0	11	11	0	11
11	0		0	0	0
12	0		0	0	0
13	0		0	0	0
14	40		40	1	39
15	87		87	41	46
16	80		80	48	32
17	0		0	0	0
18	65		65	25	40
19	104		104	59	45
20	106	37	143	100	43
21	65		65	49	16
22	0		0	0	0
23	0		0	0	0
24	0		0	0	0
25	0		0	0	0
26	0		0	0	0
27	0		0	0	0
28	0		0	0	0
29	0	62	62	n.a.	-
30	30		30	8	22
7/1	65		65	29	36
2	73		73	28	45
3	45		45	15	30
TOTALS	1084	115	1100	497	610

TABLE B-8. SUMMER PERIOD WATER BALANCES, SOUTH PLOT

Date	Wastewater (m^3)	Rain (m^3)	Total influent (m^3)	Effluent (m^3)	Evaporation and percolation (m^3)
5/29/79	24		24	0	24
30	63		63	0	63
31	63		63	19	44
6/1	63		63	26	37
2	63		63	26	37
3	63		63	25	38
4	63		63	21	42
5	42		42	14	28
6	0		0	0	
7	0	3	3	0	
8	0		0	0	
9	11		11	0	11
10	57	7	64	4	60
11	57		57	10	47
12	63		63	13	50
13	63		63	15	48
14	34		34	11	23
15	0		0	0	0
16	0		0	0	0
17	0		0	0	0
18	0		0	0	0
19	0		0	0	0
20	0	23	23	4	19
21	18		18	0	18
22	63		63	7	56
23	73		73	31	42

(continued)

TABLE B-8. (continued)

Date	Waste-water (m^3)	Rain (m^3)	Total influent (m^3)	Effluent (m^3)	Evaporation and percolation (m^3)
24	77		77	33	44
25	75		75	34	41
26	74		74	37	37
27	74		74	45	29
28	32		32	27	5
29	0	38	38	n.a.	--
30	25		25	8	17
7/1	60		60	39	21
2	66		66	40	26
3	43		43	30	13
TOTALS	1409	71	1480	519	920

TABLE B-9. PAN EVAPORATION AND EVAPOTRANSPIRATION ESTIMATES

Date	Pan evaporation		Evapotranspiration (measured)*		ET/Pan E
	cm	m^3	cm	m^3	%
9/8/78	0.74	10.4	0.34	4.8	46
9	0.97	13.6	0.55	7.7	57
10	0.58	8.2	0.20	2.8	34
11	0.64	9.0	0.24	3.4	38
12	0.33	4.7	-	-	-
13	0.61	8.6	-	-	-
14	0.05	0.7	-	-	-
15	0.25	3.5	0.18	2.5	72
16	0.41	5.8	0.18	2.5	44
17	0.41	5.8	0.30	4.2	73
18	0.30	4.2	-	-	-
19	0.25	3.5	-	-	-
20	0.43	6.1	0.09	1.3	21
21	0.66	9.3	-	-	-
22	0.10	1.4	0.14	2.0	140†
23	0.48	6.8	-	-	-
24	0.33	4.7	0.08	1.1	24
mean and standard deviation	0.49 ± 0.25		0.23 ± 0.14		50 ± 25

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* Refer to the text for method of measurement.

† 100% was used for these values to calculate means and standard deviations.

(continued)

TABLE B-9. (continued)

Date	Pan evaporation		Evapotranspiration (measured)*		%
	cm	m^3	cm	m^3	$\frac{ET}{Pan\ E} \times 100$
6/1/79	0.13	1.1	0.20	1.7	154†
2	0.25	2.2	0.15	1.3	60
3	1.02	8.9	0.28	2.4	27
4	1.14	10.0	0.75	6.5	66
8	0.23	3.2	0.24	3.4	104†
9	0.53	7.5	0.08	1.1	15
11	n.a.	-	0.13	1.1	-
12	0.71	6.2	0.53	4.6	75
13	0.84	7.3	0.39	3.4	47
15	0.79	11.1	0.50	7.0	63
16	1.27	17.9	0.35	4.9	28
19	0.56	7.9	0.46	6.5	82
23	n.a.	-	0.11	1.0	-
24	n.a.	-	0.32	2.8	-
25	n.a.	-	0.30	2.6	-
26	0.74	6.4	0.47	4.1	64
27	0.94	8.2	0.40	3.5	43
mean and standard deviation	0.70 ± 0.35		0.36 ± 0.18		56 ± 25